Research Note 84-101

Reverse Engineering of the M1 Fault Detection and Isolation Subsystem:

Human Factors, Manpower, Personnel, and Training in the Weapons System Acquisition Process

Arthur Marcus
Jonathan Kaplan

U. S. Army
Research Institute for the Behavioral and Social Sciences

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In a briefing format, this report on the M1 Fault Detection and Isolation Subsystem summarizes an examination of human factors, manpower, personnel and training (HMPT) issues during the systems acquisition process. The report is one of four reverse engineering studies prepared at the request of GEN M.R. Thurman, Army Vice Chief of Staff. The four systems were studied as a representative sample of Army weapons systems. They serve as the basis for drawing conclusions about aspects of the weapons system acquisition process which most

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affect HMPT considerations. A synthesis of the four system studies appears in the final report of the Reverse Engineering Task Force, US Army Research Institute.

The Army is introducing new weapons systems to modernize its materiel resources at the greatest rate since World War II. At the same time, the Army is redesigning its force structure (Division 86) in light of the all-volunteer force. To insure that there will be enough soldiers with enough training to man the new complicated weaponry, the Army has designed a complex materiel acquisition process. This process is supposed to introduce human factors, manpower, personnel and training (HMPT) considerations into weapons system design early enough to prevent mistakes that will affect the system's operational utility and that will also add unanticipated expense to the weapon's life cycle costs.

Despite a number of regulations and instructions to include HMPT considerations in materiel acquisitions, the Weapons System Acquisition Process (WSAP) has not always been successful in producing weapons that are readily manned and operationally useful. This is true for several reasons. Techniques for predicting manpower requirements are not adequate. The documentation of HMPT requirements is slow and complicated, and it occurs too late in the WSAP to be effective. Finally, materiel developers often fail to understand the impact of HMPT requirements on the ultimate cost and operational utility of a new piece of hardware once it is fielded. Consequently, insufficient funds and effort are devoted to HMPT analysis and human factors engineering during early stages of system development. Such analyses have

often been scrapped when hardware budgets were exceeded and production schedules were slipping. Clearly, the WSAP needed more careful examination with respect to HMPT needs.

The Reverse Engineering Project was initiated at the request of GEN Maxwell R. Thurman while he was Deputy Chief of Staff for Personnel. It was his position that careful examination of the development process of several Army weapons systems that had already been fielded would identify critical events in the WSAP.

If proper consideration were given to HMPT issues at these critical WSAP events, the Army might be more likely to field more operationally useful systems. GEN Thurman began a series of projects to examine the WSAP. The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) was already intensively involved in systems-manning technology research. ARI was assigned to do "reverse engineering" on four weapons systems: STINGER, Multiple Launch Rocket System (MLRS), BLACK HAWK (UH-60A), and the Fault Detection and Isolation Subsystem (FDIS) of the M1 tank. Reverse engineering is the process of examining a product of the WSAP and, by using documentation and data on the weapons system, to determine what was done with respect to HMPT issues and what else could or should have been done to improve the result.

This report is on the M1 Tank Fault Detection and Isolation Subsystem. The report is self-contained, as are the reports on the three other weapons systems examined by the Reverse Engineering Task Force. There is also a report synthesizing the findings across the four weapons sytems and their implications for the WSAP.

It is not the intent of this report to criticize the M1 or any of the agencies responsible for its development. It is intended, rather, that this effort focus the Army's attention on improvements that can be made in the weapons system acquisition process, by using the M1 acquisition as an example.

Executive Summary

BACKGROUND

The Army is introducing new weapons systems to modernize its materiel resources at the greatest rate since World War II. At the same time, the Army is redesigning its force structure (Division 86) in light of the all-volunteer force. To insure that there will be enough soldiers with enough training to man the new complicated weaponry, the Army has designed a complex materiel acquisition process. This process is designed to introduce human factors, manpower, personnel, and training (HMPT) considerations into weapons system design in a comprehensive fashion early enough to prevent manpower mistakes that will affect the system's operational utility or add unanticipated expense to the weapon's life cycle costs.

The Reverse Engineering Project was initiated at the request of GEN Maxwell R. Thurman while he was Deputy Chief of Staff for Personnel. It was his position that careful examination of the development process of several Army weapons systems that had already been fielded would identify critical events in the Weapons System Acquisition Process (WSAP). If proper consideration were given to human factors, manpower, personnel, and training issues at these critical WSAP events, the Army might be more likely to field more operationally useful systems. GEN Thurman began a series of projects to examine the WSAP. The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) was already intensively involved in systems-manning technology research. ARI was assigned to undertake a study based on the

"Reverse Engineering" of four weapons systems: STINGER, Multiple Launch Rocket System (MLRS), BLACK HAWK (UH-60A), and the M1 Fault Detection and Isolation Subsystem (FDIS). Reverse engineering is the process of examining a product of the WSAP and, by using documentation and data on the weapons system, to determine what was done with respect to HMPT issues and what else could or should have been done to improve the result.

APPROACH

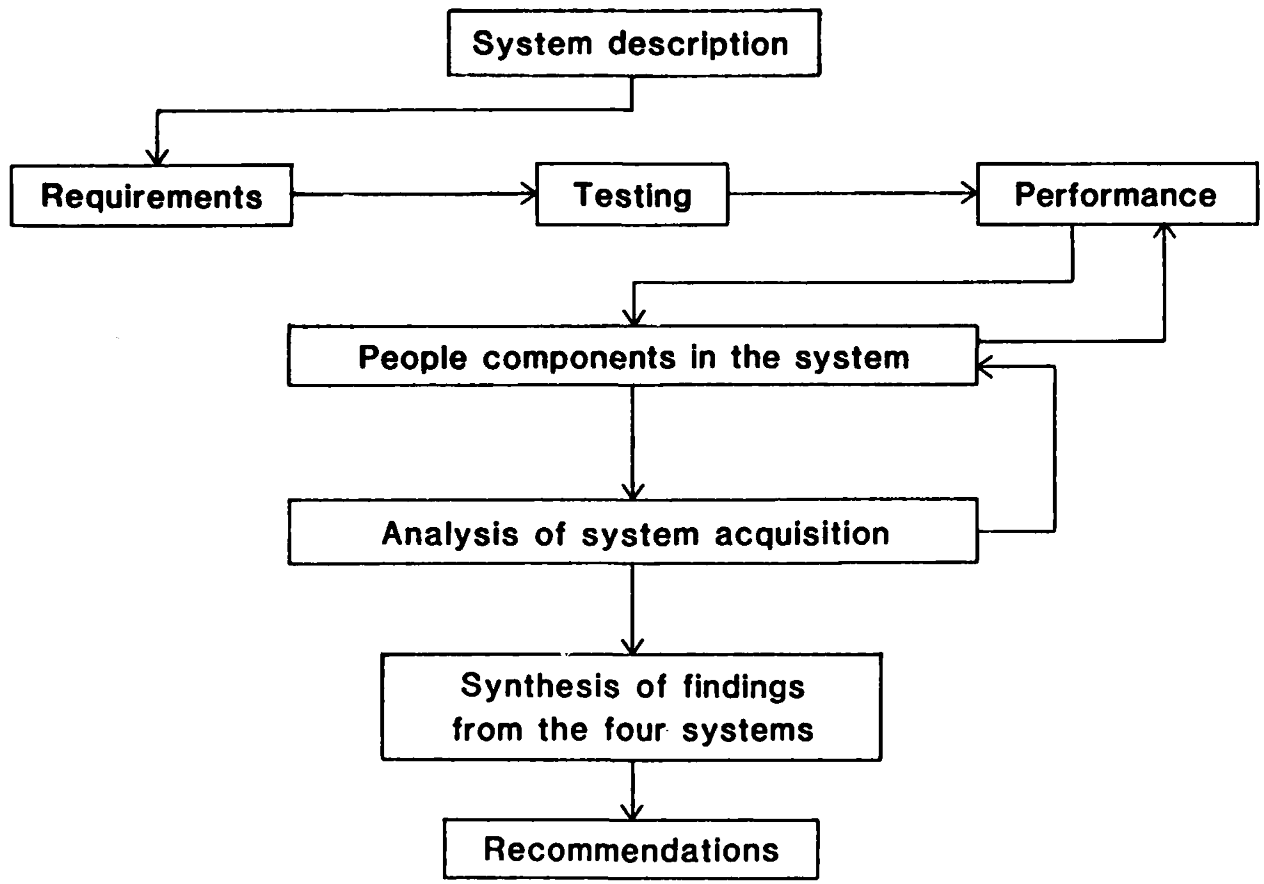
This report summarizes the study of the M1 Fault Detection and Isolation Subsystem. Similar reports address the other three weapons systems encompassed by the Reverse Engineering Project. All four studies followed the same general approach illustrated in the figure below:

- The system was defined and described.
- Requirements documents were reviewed to determine how system performance was specified.
- Test and evaluation data were analyzed and compared to performance criteria.
- Problem areas in system performance were identified.
- HMPT factors were examined for their impact on the problematic aspects of system performance.
- The WSAP was reviewed to identify those facets that contributed to HMPT issues.

Findings from the four system studies were synthesized to arrive at conclusions regarding generic problems in the WSAP related to HMPT. Recommendations were developed for methods to improve the process

GENERAL APPROACH—REVERSE ENGINEERING

- STINGER
- Multiple Launch Rocket System
- BLACK HAWK
- M1 Fault Detection and Isolation Subsystem



from an HMPT perspective. This information is summarized in the final report of the Reverse Engineering Task Force.

It is not the intent of the study or this report to criticize the M1 or any of the agencies responsible for its development. Instead, it is hoped that this effort will help focus the Army's attention on improvements that can be made in the weapons system acquisition process.

MAJOR FINDINGS

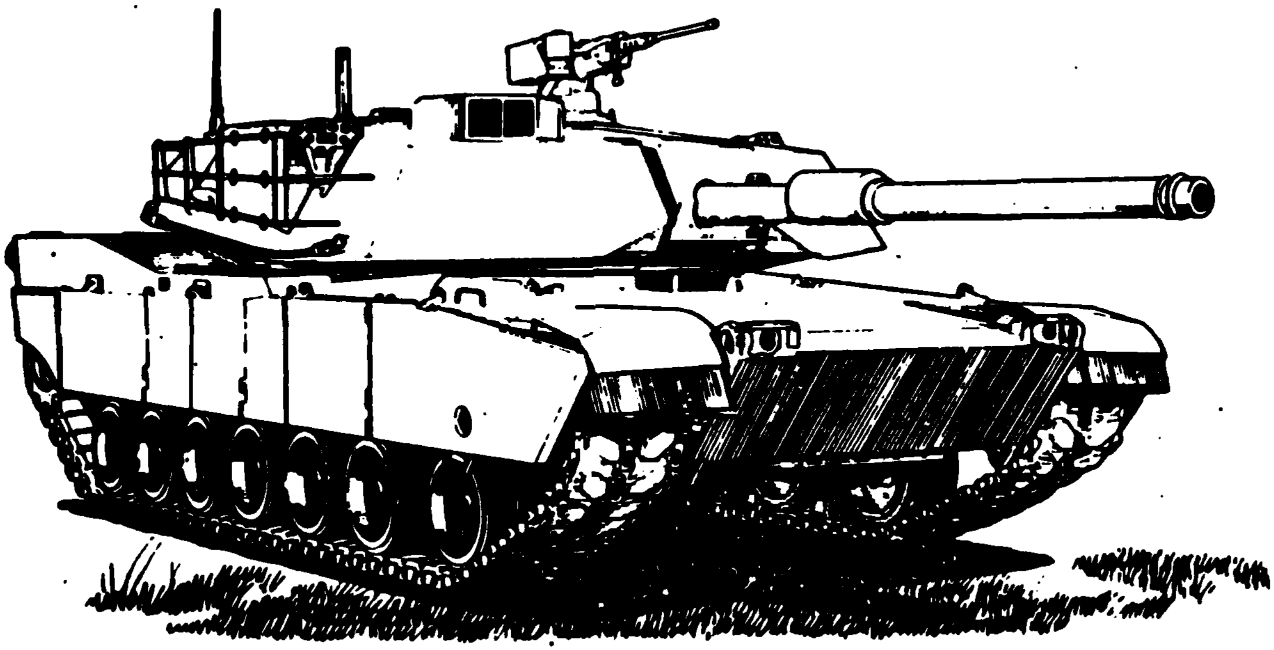
Tank hardware considerations were the driving force in the M1 development and acquisition cycle. In the main, HMPT considerations had negligible influence on either the design or development of the fault detection and isolation capabilities of the M1. A systematic effort was not made early on to integrate requirements for test, measurement, and diagnostic equipment (TMDE) hardware with those for maintenance personnel, test procedures, or necessary technical documentation.

Built-in test equipment (BITE) and TMDE requirements or constraints were never meaningfully defined or specified in the system requirements documents or during early contractual development efforts. Also, criteria were never established for BITE/TMDE or soldier performance during developmental and operational testing, and decisionmakers were not given meaningful information to judge the effectiveness of BITE/TMDE performance in the hands of soldiers.

Many HMPT related deficiencies associated with the M1 fault detection and isolation capability can be traced to a Program Management decision calling for the postponement of Integrated Logistics System development until the start of Full-Scale Engineering Development. This decision, coupled with the low visibility given HMPT considerations during the early stages of system development, set the stage for the BITE/TMDE and maintainer troubleshooting problems that would follow.

In part, decisions concerning HMPT requirements could not be reliably formulated because reliability, availability, and maintainability (RAM) data collected did not include effective measures of realistic operational supportability. Additionally, there was a failure on the part of the HMPT community to articulate and implement necessary front-end analysis requirements effectively.

M1 FAULT DETECTION AND ISOLATION SUBSYSTEM



M1 Tank

Organization of this Report

This report in a briefing format on the M1 Tank Fault Detection and Isolation Subsystem (FDIS) summarizes an examination of human factors, manpower, personnel, and training (HMPT) issues in the Weapons System Acquisition Process (WSAP). The report is one of four reverse engineering studies prepared at the request of GEN Maxwell R. Thurman, Army Vice Chief of Staff. The four systems were studied as a representative sample of Army weapons systems and serve as the basis for drawing conclusions about aspects of the WSAP that most affect HMPT considerations.

This report begins with a brief description of the M1 Tank System and the requirements for a "subsystem" capability or means to detect, isolate, and identify faults occurring within the tank. This is followed by a discussion of the built-in test equipment (BITE) and test, measurement, and diagnostic equipment (TMDE) concept implemented on the M1. A history of the M1 acquisition cycle is presented next to demonstrate how early design decisions influenced overall system development. Past and current data on subsystem performance in general, and with respect to the impact it has had on reliability, availability, and maintainability (RAM) and HMPT issues, are then presented. The report concludes with a summary of findings.

OUTLINE

- M1 System Description
- Fault Detection and Isolation Subsystem
- M1 Concept of Built-in Test Equipment/ Test Measurement and Diagnostic Equipment (BITE/TMDE)
- Acquisition Cycle History
- Subsystem Performance
- Summary and Conclusions

The M1 is a 60-ton, highly mobile, fully tracked armored fighting vehicle incorporating improvements over the M60A1 in fire control, power plant, suspension system, and armor protection. The M1 consists of a hull and turret (fighting compartment) and is operated by a four-person crew (tank commander, gunner, loader, and driver MOS 19K).

The M1 achieves its ability to fire accurately on the move by stabilizing the main gun to a stabilized gunner's sight. The main armament is a 105mm M68 gun, but the turret is capable of mounting a 120mm gun of either German or British design (in the latter instance it is essentially the M1E1). Secondary armament consists of a .50 cal machinegun at the commander's station, a coaxial machinegun, and a pintle-mounted weapon at the loader's station.

The M1 is powered by a 2500 lb regenerative cycle gas turbine engine, which can produce 1500 hp with a 2000 lb saving in engine weight over a comparable diesel engine. The reduced engine weight allows for the use of more protective armor. The M1 provides 25 hp per ton versus 15 hp per ton that is available with the M60. The M1 is capable of speeds up to 45 mph on hard surface roads and up to 30 mph cross-country.

Added armor increases resistance to penetration. Spaced armor is used to protect key components. Compartmentalization of both fuel and ammunition increases the survivability of crew and critical components. Blowoff vents are used to relieve explosion pressures. Each round is stored in separate aluminum sleeves to prevent sympathetic explosions. The fire extinguisher is activated by infrared optical sensors.

The M1 features designed-in fault-isolating sensors for fire control, engine, transmission, and thermal-imaging system problems. The onboard ballistics computer automatically administers self-checks and indicates system malfunctions. This self-check does not depend on the computer to function. A numeric problem code is displayed to the operator to assist diagnosis.

M1 SYSTEM DESCRIPTION

- o Incorporates improvements over the M60
- o Operated by a four-person crew
- o Uses 105mm gun as main armament
- o M1E1 (under development) will incorporate 120mm gun
- o Maintainability designed into tank
  - -- Onboard malfunction detection

OUTLINE

M1 System Description

Fault Detection and Isolation Subsystem

M1 Concept of Built-in Test Equipment/
Test Measurement and Diagnostic
Equipment (BITE/TMDE)

Acquisition Cycle History

Subsystem Performance

Summary and Conclusions

One of the great difficulties in maintaining complex electronic and mechanical equipment is the recognition of symptoms of malfunctioning and the interpretation of their significance. Troubleshooting is a difficult process that requires numerous skills and is characterized by many uncertainties and opportunities for error. The need for an integrated approach to developing fault isolation systems cannot be sufficiently stressed.

One of the approaches used to improve readiness through maintainability in the M1 Tank emphasizes the use of BITE in the form of equipment built into the tank, coupled with a fault isolation testing capability consisting of automatic test equipment (ATE) brought to the tank for maintenance purposes.

For this approach to work, factors such as the skills of available maintenance personnel, their training, the maintenance concept to be employed, appropriate establishment of fault detection thresholds (to include specification of tolerable false alarm rates), impact of spares and transportation needs as a function of repair concept, etc., must be carefully considered and specified early on during system development.

FAULT DETECTION AND ISOLATION SUBSYSTEM

Definition

A test and diagnostic approach designed as a complete subsystem is totally integrated with the prime system. It places special emphasis on the people involved and includes a number of different aids (built-in test equipment, test measurement and diagnostic equipment, special tools, technical manuals, procedures, etc.) for discovering and diagnosing malfunctions.

The Materiel Need (MN) Statement originally prepared in 1972, with revisions in 1975 and 1980, called for 90% of all malfunctions to be detected and corrected at operator/organizational level. The main battle tank (MBT) design was to incorporate ease of maintenance to achieve high availability rates. BITE sensors and measuring devices (which were never meaningfully or objectively defined), which permit the crews to detect the location of faulty equipment quickly and precisely, were to be a feature of the new MBT. It was envisioned that checking instruments on the driver's panel, for example, could help determine the status of a particular component. Built-in indicators and test equipment were supposed to provide a crewmember with the capability of going directly to the problem, without having to troubleshoot the system in addition to making routine checks.

The maintenance support positive (MS+) concept of modular replacement (with a fix forward, repair to the rear emphasis) was specified.

No specific statements were made about support and TMDE in the original MN other than to say that the design would require the least amount of specialized support and test equipment. The 1975 revision to the MN states that trade-off studies would be required to develop the most cost effective support possible. A statement was also made in this revision regarding the need for preparing Technical Manuals (TMs) in accordance with skill performance aids (SPA) formats and that draft publications of these manuals would be required in time to support developmental and operational test (DT/OT) II training.

The competitive RFP (1973) indicated that development of peculiar support equipment--tools, test sets, etc.--common support equipment, and spare and repair parts were not applicable to the prototype validation phase.

FAULT DETECTION AND ISOLATION SUBSYSTEM

What Was Specified

Materiel Need Requirements (Logistical Concept)

- 90% of all malfunctions detectable and correctable at operational/organizational level
- Built-in test equipment to be incorporated in design where-ever practicable
- Design to require least amount of specialized support and test equipment
- Maintenance support plus concept of modular replacement
- Main battle tank design to incorporate ease of maintenance

The draft development plan of the Main Battle Tank Task Force (MBTTF) (1972) contained a very ambitious human factors engineering plan, which was to be administered on a coequal basis with other engineering specialty programs (such as maintainability and reliability) and was to be coordinated with these programs. In addition to human factors engineering objectives, certain manpower, personnel, and training issues were touched upon, but no provisions were made for implementing or testing them. Other portions of the MN covering HMPT issues indicated that the M1 crew would have essentially the same duties as the crew of the M60A1 tank and that the MOS structure would be similar to other fielded tank systems. However, the turret controls and fire control system could be more or less complex than that found in the (then to be fielded) M60A2 tank. In addition, it was stated that a minimal number of training devices would be required to update existing MOS, including a turret trainer for crew familiarization and maintenance training, a conduct of fire trainer (COFT), and a driver station trainer. The 1975 MN revision by the Tank Special Study Group (TSSG) indicated that as hardware concepts were developed, design and support decisions would be made with due consideration for their impact on manpower and training requirements.

FAULT DETECTION AND ISOLATION SUBSYSTEM

What Was Specified

Material Needs Requirements (HMPT)

- o Operational and maintenance characteristics are similar to M60A1.
- o MOS training at organizational level must emphasize trouble-shooting and diagnostic procedures.
- o New or revised MOS may be required for maintenance support.
- o Minimal amount of training devices will be required to update existing MOS.
- o Main battle tank personnel and training concepts to be based upon results of maintainability and reliability trade-off studies.

OUTLINE

M1 System Description

Fault Detection and Isolation Subsystem

M1 Concept of Built-in Test Equipment/ Test Measurement and Diagnostic Equipment (BITE/TMDE)

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Summary and Conclusions

The M1 Maintenance System employs the following four levels of support:

Crew/Organizational Maintenance. Through the design of highly reliable indicators, maintenance at this level will begin with daily crew checks. The onboard ballistic computer is designed to monitor the operational state of the fire control system continuously. In the event of a malfunction, the computer, upon interrogation, will automatically identify faulty subsystems, permitting continued operations by manual input of data, alternative modes of operation, or corrective actions.

Direct Support Maintenance. Maintenance at this level is limited to end-item repair (unscheduled maintenance) by component replacement. Repair is limited by the availability of special tools, test equipment, and skills required.

General Support Maintenance. Common components and piece parts will be repaired at the general support (GS) level for return to stock. Rebuilding major components is not authorized at this level.

Depot Maintenance. Overhaul of end items and major components is accomplished at this level, as well as piece-part repair of any component requiring extensive calibration or alignment. Included are any repairs in excess of GS maintenance-level authorizations.

M1 CONCEPT OF BUILT-IN TEST EQUIPMENT/TEST MEASUREMENT AND DIAGNOSTIC EQUIPMENT

Maintenance Ground Rules

- Built-in test equipment sensors and measuring devices are considered to be an integral part of the operational system.
- Replacement and repair will take place at the lowest practical echelon, consistent with maintenance skill.
- Four levels to be employed:
  - -- Crew/organizational
  - -- Direct support
  - -- General support
  - -- Depot

M1 Concept of BITE/TMDE

There are two types of BITE on the M1: automotive BITE (visual status indicators) and fire control system BITE (manually initiated built-in test sequence).

The M1 also utilizes three types of automatic test equipment:

1. Simplified Test Equipment (STE/M1)
2. Direct Support Electrical System Test Set (DSESTS)
3. Thermal System Test Set (TSTS)

M1 CONCEPT OF BUILT-IN TEST EQUIPMENT/TEST MEASUREMENT AND DIAGNOSTIC EQUIPMENT

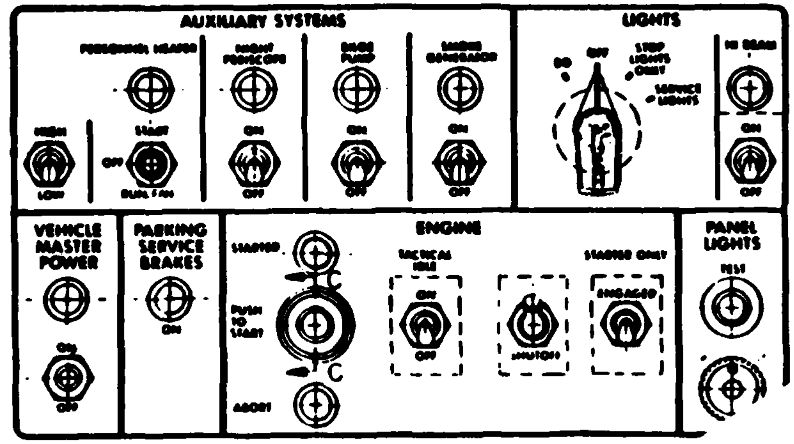
Functional Description

- o Built-in Test Equipment (BITE)
  - -- Automotive BITE
  - -- Fire Control System BITE
- o Test Measurement and Diagnostic Equipment (TMDE)
  - -- Simplified Test Equipment Test Set (STE/M1)
  - -- Direct Support Electrical System Test Set (DSESTS)
  - -- Thermal System Test Set (TSTS)

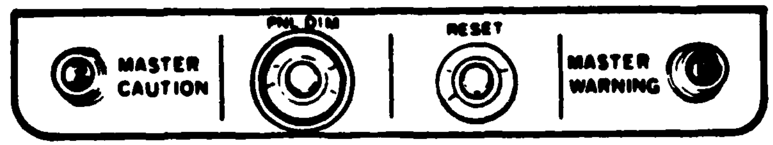
AUTOMOTIVE BITE

The driver's daily maintenance activities include the use of BITE and visual indicators. This reduces the time to perform daily crew checks of crew compartment filters, fluid levels, and fire extinguisher readiness. BITE permits the driver to check vehicle status from his seat without gaining access to the engine. The maintenance monitor section of the instrument panel provides light-emitting diode (LED) malfunction indications for 12 vehicle functions, allowing the driver to monitor various hull/powerpack maintenance-required parameters without access to the engine compartment. These indicators work in conjunction with warning lights located on the driver's alert panel. Should a malfunction occur (i.e., ENGINE OIL--LOW), an amber maintenance indicator will illuminate on this panel, along with a large MASTER CAUTION amber light (located on the ALERT panel directly in front of the driver) for high visual prominence. The MASTER CAUTION light can be extinguished by a reset button on the ALERT panel; however, the individual maintenance indicator will remain on until the fault has been corrected. Proper servicing, such as adding engine oil, will extinguish the ENGINE OIL--LOW indicator. The large MASTER WARNING red light, also located on the ALERT panel directly in front of the driver for high visual prominence, illuminates simultaneously with any of the red warning lights on the instrument panel. The reset capability for both the MASTER CAUTION light and the MASTER WARNING light prevents any masking condition should a second fault occur prior to the first problem being cleared.

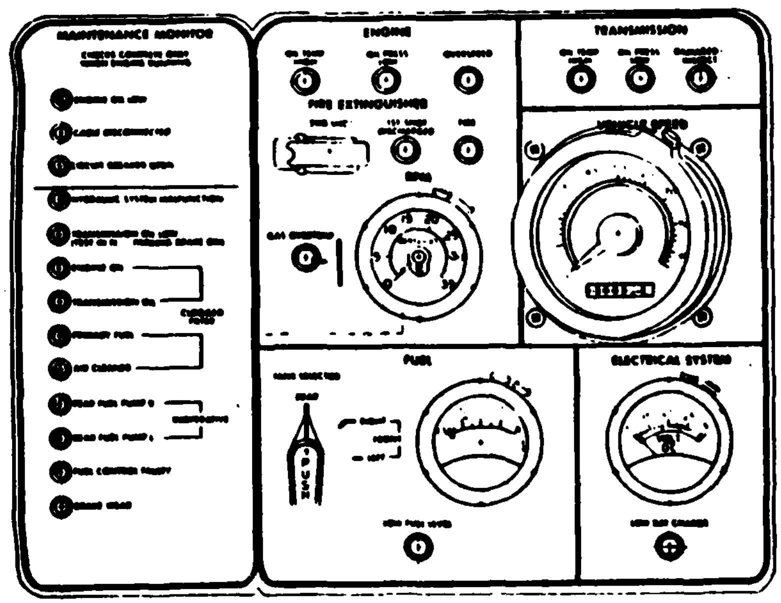
DRIVER'S MASTER PANEL



DRIVER'S ALERT PANEL



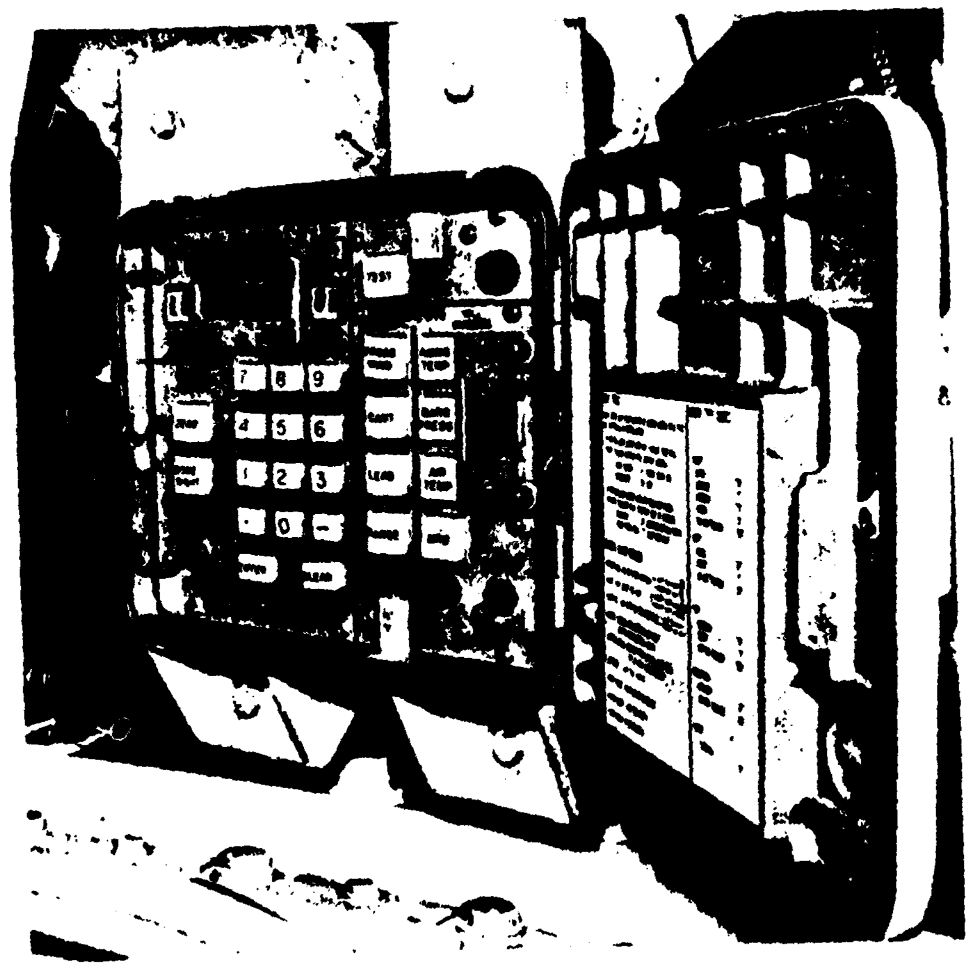
DRIVER'S INSTRUMENT PANEL



FIRE CONTROL SYSTEM BITE

BITE continuously monitors the status of the fire control electronics and will on command fault-isolate the system. Continuous automatic malfunction detection capability is incorporated in the fire control system to identify to the commander if and when a gross malfunction has occurred in the ballistic computer system and other major components. A manually initiated built-in test sequence actively exercises the ballistic computer, cant sensor, crosswind sensor, laser rangefinder, gun/turret drive system, line of sight (LOS) stabilization system, data link, and the gunner's primary sight (GPS) reticle drive and compares their individual responses to a predetermined pass/fail criterion. Failure sources are identified by a number code in the computer control panel for appropriate repairs. Manual override capability for the automatic inputs of cant angle, crosswind velocity, lead rate, and range is provided for emergency operation.

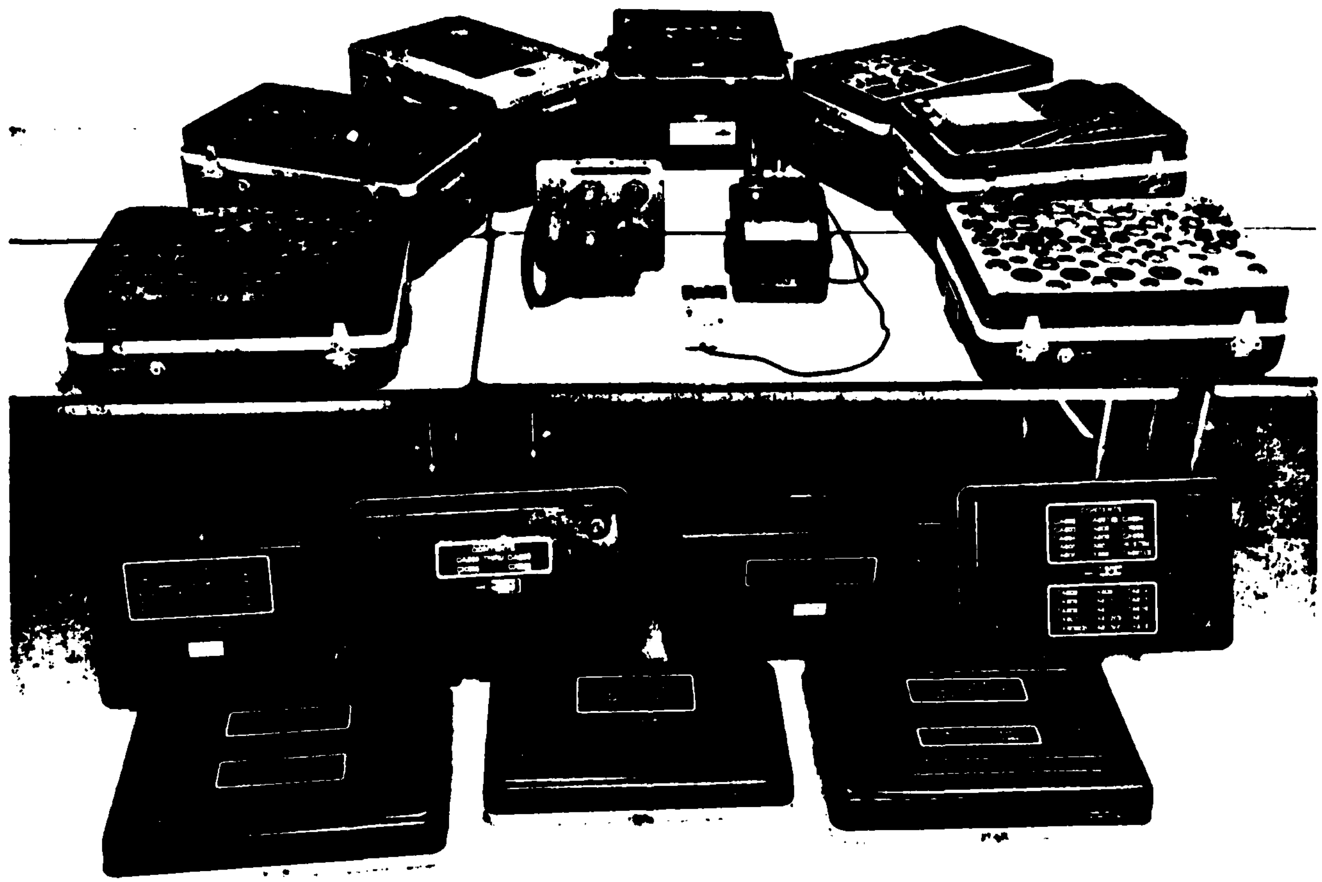
The fire control system self-test is initiated by pressing the test key on the computer control panel. Code information is contained on the panel cover. Manual input capability through this panel allows the fire control system to function properly in a slightly degraded mode in the event of a sensor failure.



Computer Control Panel, Manual Controls

TEST, MEASUREMENT, AND DIAGNOSTIC EQUIPMENT: STE/M1 TEST SET

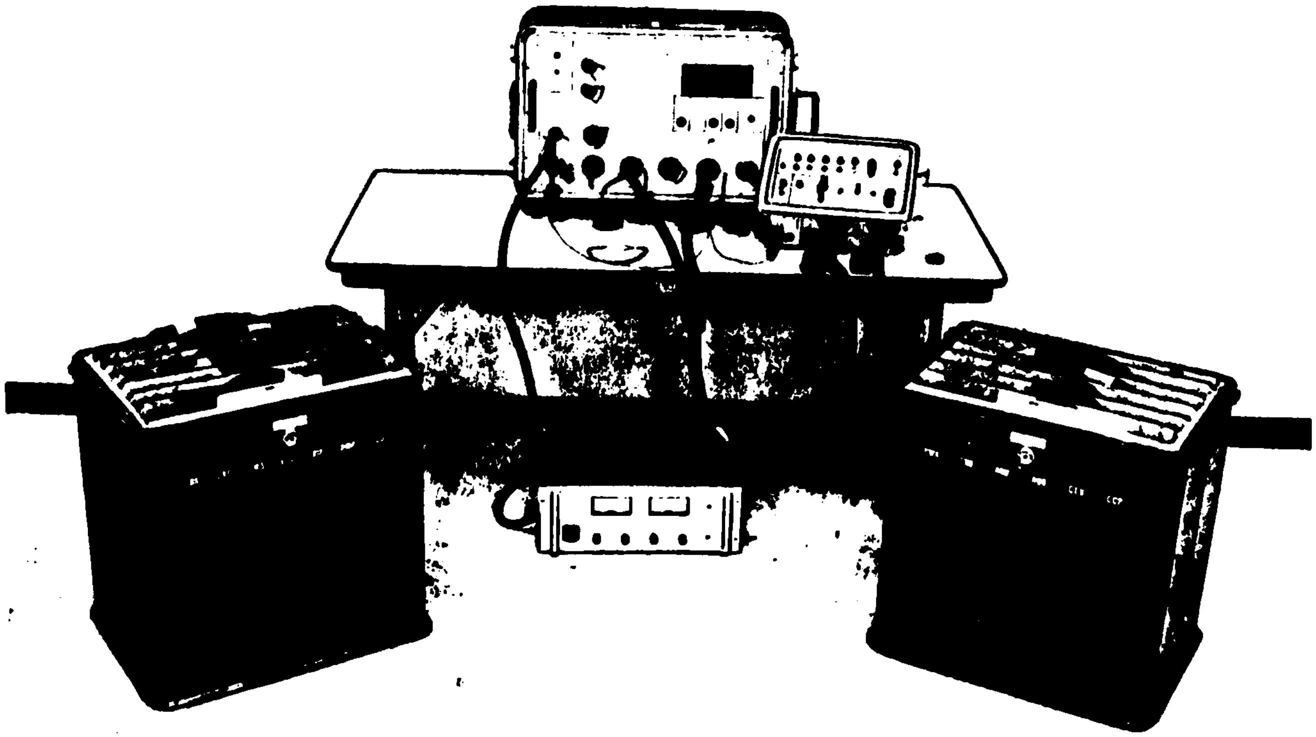
The Simplified Test Equipment (STE/M1) Test Set is a semi-automatic test set consisting of a vehicle test meter, controllable interface box, set communicator, and 140 associated adapters and cable assemblies (seven major assemblies in all). This equipment is used by organizational level maintenance personnel to diagnose hull and turret electrical systems, cables, fire extinguisher, fire control computer, rangefinder, and engine problems in the tank. A total of 35 tank systems and subsystems can be evaluated with this test set. An automatic self-test is run when the equipment is turned on, and additional confidence testing may be performed during operation. Performance testing is used to check overall vehicle readiness.



STE/M1/FVS Test Set

TEST, MEASUREMENT, AND DIAGNOSTIC EQUIPMENT: DSESTS

Direct Support Electrical System Test Set is a portable automatic test set used by direct support/general support (DS/GS) maintenance personnel to fault-isolate components removed from the tank system. DSESTS consists of three cases: an electronics unit and two cases containing cables. Using micro-computer technology, this test set provides a menu for selection of test programs. The sequence of each test is controlled automatically from the electronics unit, as is the application of required power, signal stimuli, and measurement interfaces. This is accomplished through a dedicated test cable for each of the 12 line replacement units (LRUs) tested. Testing continues as long as results are within acceptable stored limits. Unacceptable measurements terminate the test and display a failure message on the front panel of the DSESTS.



DSESTS Test Set

TEST, MEASUREMENT, AND DIAGNOSTIC EQUIPMENT: TSTS

The Thermal System Test Set is intended for use in servicing the night vision Thermal-Imaging Subsystem (TIS). As presently conceived, it will provide DS-level fault isolation of the TIS. Only a "hot mock-up" of the Thermal-Imaging Subsystem Test Set (TISTS) is available for use.

OUTLINE

M1 System Description

Fault Detection and Isolation Subsystem

M1 Concept of Built-in Test Equipment/
Test Measurement and Diagnostic
Equipment (BITE/TMDE)

Acquisition Cycle History

Subsystem Performance

Summary and Conclusions

In January 1972 the Chief of Staff of the Army established the Main Battle Tank Task Force to define requirements for a new MBT. Twice before the Army was unsuccessful (MBT 70/M803) in developing a new tank to replace the M60 series tanks. After an accelerated conceptual phase (January-July 1972) the MBTTF produced its final report, which included the system Materiel Need (Engineering Development) (MN(ED)). An advanced development (AD) phase contract was entered into with General Motors and Chrysler in June 1973. Contractors were given tremendous latitude during the 34-month validation phase to convert paper concepts into hardware and demonstrate their design for full-scale engineering development (FSED). The only constraints were in the form of prioritized design characteristics (trade-offs among these were allowed) and a recognition that costs must be limited.

In the interest of saving costs, the AD contracts did not call for the contractors to develop Integral Logistics System (ILS) packages for evaluation at DT/OT I. Since only one of the two prototypes would be selected for FSED, it was reasoned that purchase of two ILS packages would be redundant. ILS development was to be postponed until FSED. The M1 Program Management Office (PMO) estimates that as much as $30 million was saved during the validation phase by postponing the ILS effort.

ACQUISITION CYCLE HISTORY

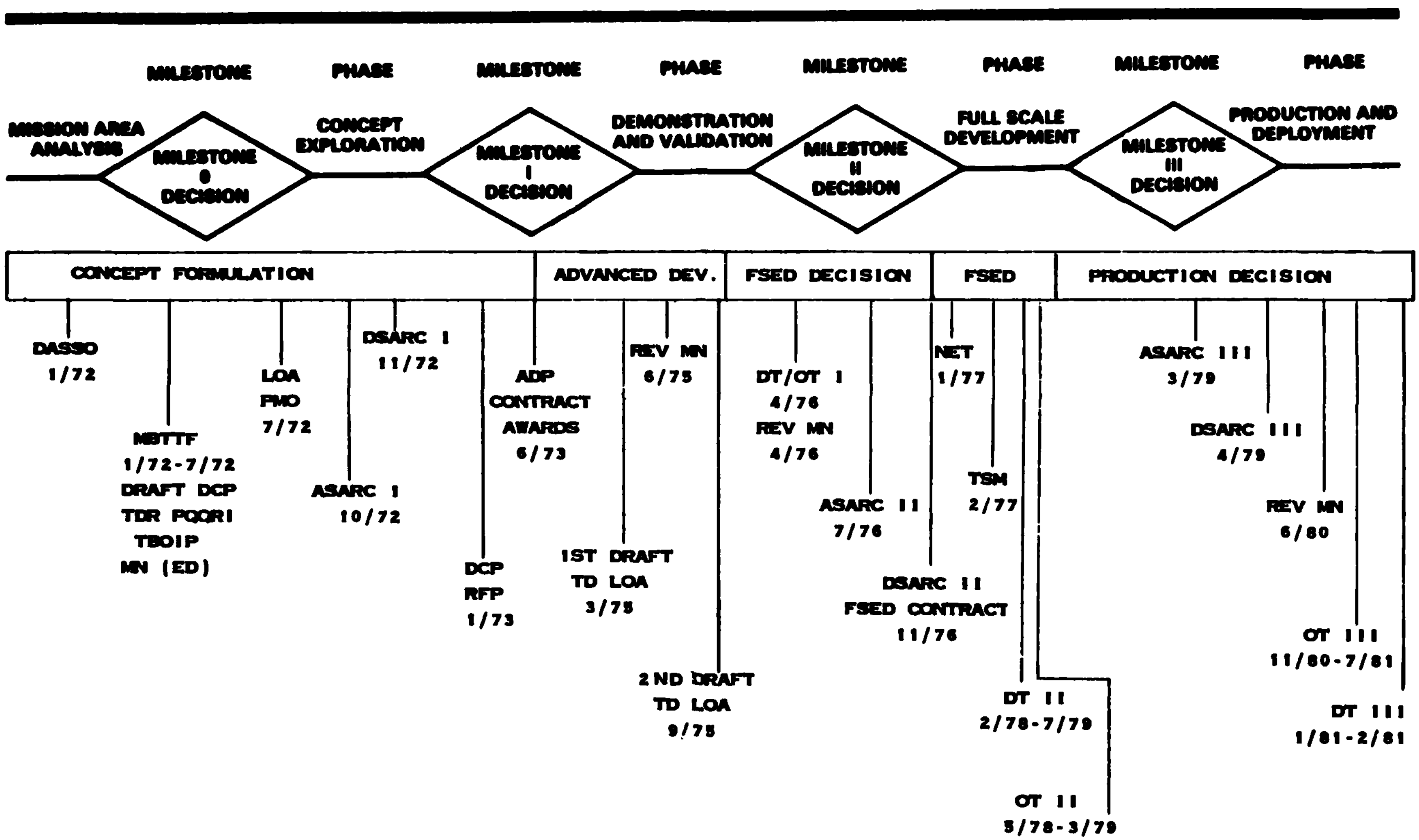
Background

- o Main Battle Tank Task Force established (1972)
- o Accelerated conceptual phase
- o 34-month validation phase
  - -- Competitive prototype approach
  - -- Increased contractor responsibility
  - -- Design to unit production cost goal
- o Decision not to fund for logistics support

Rather than being event-driven, as called for in the Life Cycle System Management Model (LCSMM), the M1 development program was time-driven by hardware, system performance requirements, and cost schedule constraints. HMPT development milestones were sometimes bypassed when they were not completed. Because HMPT-related development was closely tied to the ILS program, it consistently lagged behind materiel development from the time the decision was made to omit the ILS package from the AD contracts for demonstration and validation.

M1

MAJOR ACQUISITION PHASES AND MILESTONES



It is interesting to note that the logistics design parameter entitled "Compatibility with Associated Equipment" ranks last in the priorities established by the Army. Because the M1 was probably the first major armored ground system to emphasize and incorporate advanced technology equipment into its design, perhaps more, rather than less, emphasis should have been given to this item. As a consequence, contractors concentrated primarily on operations and system performance requirements.

ACQUISITION CYCLE HISTORY

XM-1 Advanced Development Design Characteristics, in Order of Priority

Main Battle Tank Task Force (1972)

1. Fire power
2. Mobility
3. Crew survivability
4. Reliability, availability, maintainability (RAM)
5. Cost
6. Weight
7. Equipment survivability
8. Improvement potential
9. Human engineering
10. Transportability
11. Compatibility with associated equipment

In August 1974 CSA asked the Commanding General, TRADOC, to review and analyze M1 user requirements to insure there was still complete agreement. The Tank Special Study Group (TSSG) was formed to conduct this review, which would revalidate the original requirements of the 1972 MN(ED). Along with a revised MN (ED), a new set of design requirements and order of priority was drafted in June 1975. Once again logistics considerations fall short. Out of 19 design requirements, diagnostic aids ranked 16th and support equipment ranked 18th. A detailed analysis of the impact of M1 on the logistics system was not undertaken, and the minimal analysis that was made in this area concentrated on the hardware requirements imposed by the need for increased fuel and ammunition.

ACQUISITION CYCLE HISTORY

M1 Design Requirements Priority

Tank Special Study Group (1975)

1. Crew survivability
2. Surveillance and target acquisition performance
3. First- and subsequent-round hit probability
4. Time to acquire and hit
5. Cross-country mobility
6. Complementary armament integration
7. Equipment survivability
8. Environmental impact
9. Silhouette
10. Acceleration and declaration
11. Ammunition storage
12. Human factors
13. Producibility
14. Range
15. Speed
16. Diagnostic aids
17. Growth potential
18. Support equipment
19. Transportability

Other than specifying in the 1972 MN(ED) that "new or revised MOSs may be required for maintenance support" and that "MOS training at organizational level must emphasize troubleshooting and diagnostic procedures," little of the early requirements documents made provision for how these requirements were to be satisfied or further analyzed. In TSSG's 1975 revision to the MN, personnel and training issues were addressed, but they were not of primary importance. This version showed no change in the number or skill requirements of armor crewmen (identified as MOS 11E). The executive summary contained no reference to personnel and training issues. While reliability, availability, maintainability, and durability (RAM-D) questions were addressed, they were not directly related to personnel. The tentative Basis of Issue Plan (BOIP) stated that "the impact of personnel has not been determined." This same BOIP indicated that "tools and test equipment have not been identified."

Because of the development shortcomings, hardly any maintainer performance analysis was accomplished early in the program. DoD directives and Army Regulations require that an ILS plan (to include maintainability support) be developed for each system and be made an integral part of systems acquisition and operation. DoD Directive 4100.35 made this a requirement for major acquisitions in 1970. Due largely to the lack of funds for ILS front-end logistics planning (and its relation to HMPT considerations) continuing development of HMPT requirements was significantly delayed.

During the initial competition, contractors concentrated primarily on hardware performance requirements. Because of contractors' latitude to design prototypes as they saw fit and the Army's lack of emphasis on HMPT considerations, development of HMPT issues was impeded. When Chrysler Defense Engineering became the prime contractor, it did not always employ the total systems approach as exemplified by the dispersion of responsibilities in test set design. Nor did Chrysler always actively involve its human factors personnel. This may be due to the fact that human factors engineering was not ranked very high by Army staff in their prioritized design characteristics. The Human Engineering Laboratory (HEL) in their human factors engineering analysis concluded that in spite of some deficiencies, the M1 was probably the best human-engineered fighting vehicle in the Army inventory. Nevertheless, human factors aspects of test equipment were never fully addressed.

ACQUISITION CYCLE HISTORY

Subsystem Development Overview

- o Early requirements documents neglected maintainer performance
- o Funding constraints prevented proper Integrated Logistics System effort
- o Compressed schedule adversely affected human factors, manpower, personnel, and training development
- o *Lack of total* systems approach
- o Human performance criteria not well established
- o Inadequate testing for logistics supportability

Human performance criteria during FSED were not well established due to the following:

- The data item description (DID) chosen for task analysis did not adequately define the levels of human behavior in operations and maintenance to be reported.
- There was no requirement to document fully the time required for the performance of each task.
- Critical tasks were not identified.
- Contractor verification of the task analysis or other integrated technical documentation and training was not required.

Because of inadequate testing of logistics supportability, the Army has had difficulty validating the types, quantities, and skill levels of personnel required to support M1 Fault Detection and Isolation. The evaluation of organizational level tasks (largely troubleshooting, fault isolation, and replacement of faulty components) has been hampered by the problems associated with test sets and TMs. The objective of the DT/OT I test was to provide information on crew-level maintenance and system failures. Subsequent tests were to include effective measures of realistic operational supportability. The heavy involvement of contractors made it difficult to assess accurately RAM in most DT/OT testing, and therefore personnel support requirements also could not be adequately assessed. The M1 Training Plan, at this date, has still not been validated.

ACQUISITION CYCLE HISTORY

Subsystem Development Overview

- Early requirements documents neglected maintainer performance
- Funding constraints prevented proper Integrated Logistics System effort
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- Inadequate testing for logistics supportability

The MBTTF MN(ED) in 1972 recognized the requirement for training devices but not in any detail. The master schedule called for the U.S. Army Training and Doctrine Command (TRADOC) to submit training device requirements (TDRs) to HQDA in May 1974. TRADOC moved slowly in developing these requirements and lost the opportunity to incorporate TDRs into the FSED RFP or the FY 77 budget. There was a debate within TRADOC concerning onboard training (simulation) versus classroom simulation. TRADOC's Deputy Chief of Staff, Training (DCST), requested that TSSG consider the former approach, but this would require modification of the tank design. The PM M1 was not favorably disposed to this request. The Armor School, which had reservations about maintenance training simulators as well as integrated technical documentation and training (ITDT), did not want to take a firm stand on maintenance trainers until ITDT was validated. The Armor School traditionally has preferred training programs that rely almost exclusively on production hardware. For example, the M60 program uses few maintenance training devices. Despite the fact that a first draft of an LOA (May 75) indicated that "emphasis of device development will be on simple, easy to operate, easy to maintain devices at unit level [to support crew, organizational maintenance and DS/GS maintenance training]," a second draft LOA (September 75) omitted all reference to maintenance trainers. The change presumably was due to the stand taken by the Armor School. In January 1978, HQDA approved draft TDRs submitted by TRADOC in July 1977.

ACQUISITION CYCLE HISTORY

Training Device Development

- Main Battle Tank Task Force cites need for training devices.
- TRADOC had internal disagreements regarding training devices.
- There was failure to articulate device development requirements.

Because ILS development was to be deferred until FSED, data required to initiate development of task analysis, maintenance manhour requirements, TMs, level of maintenance analysis, and the maintenance allocation chart were not available at the beginning of this phase. Additionally, only limited logistic support analysis (LSA) data requirements were specified in the contract, and furthermore, LSA implementation would come too late to significantly influence development of logistics support resources. Maintenance planning (rather than being based on documented LSA) evolved segmentally over a period of years from the basic design of the prototype vehicle. Test sets were not developed as an integral part of the design effort, were characterized by the dispersion of responsibilities through subcontracts, and consistently lagged behind schedule. Chrysler Sterling Defense Division was the prime contractor with the following subcontractors responsible for developing test sets and manuals: Chrysler-Huntsville (3), AVCO-Lycoming (2), Westinghouse Electric Corporation (1), and Hughes Aircraft Company (1).

Because a prototype tank was not available to support the development of test sets, only minimal tests were accomplished. Although many deficiencies were identified, there was not enough time to redesign test sets and manuals before DT/OT II testing began in 1978 and 1979. The constraints imposed by the compressed system development and testing schedule resulted in maintainability and supportability testing being sometimes limited, deferred or not conducted in the prescribed sequence. OT testing could not be conducted as thoroughly as required since DT was often conducted concurrently, resulting in some system redesign. Consequently, problems identified in one phase of testing continued into successive stages without being successfully resolved.

FULL-SCALE ENGINEERING DEVELOPMENT CONTRACT PHASE

- Limited logistics support analysis data requirements in contract
- Maintenance planning not based on documented logistics support analysis
- Test sets not developed as integral part of tank hardware design effort
- Major logistics problems found during DT/OT II testing
- Program manager establishes Automatic Test Equipment office--October 1978
- $12M programed to redesign and consolidate test sets
- Troubleshooting Task Force established--June 1980

In October 1978, the Systems Engineering Division within the Program Management Office established an ATE office which assumed responsibility for test set development. At this time the M1 was supported by seven different items of test equipment. Management decisions based upon the results of DT/OT II testing reduced the number of test sets being developed to support the tank during DT/OT III to three. The test sets were to be compatible with test equipment supporting current and future vehicle systems (e.g., common test sets for M1; fighting vehicle system (FVS)).

In 1979 $12 million was programed to redesign and consolidate test equipment, and $1.2 million to develop backup manual fault-isolation procedures. Some of the monies originally allocated to the test set equipment program were reallocated to tank hardware development.

In June 1980, a Troubleshooting Task Force (which was given an M1 tank for validation of STE/M1 software) was formed and a system of test set incidents reports was established. This effort ran through July 1982.

FULL-SCALE ENGINEERING DEVELOPMENT CONTRACT PHASE

- Limited logistics support analysis data requirements in contract
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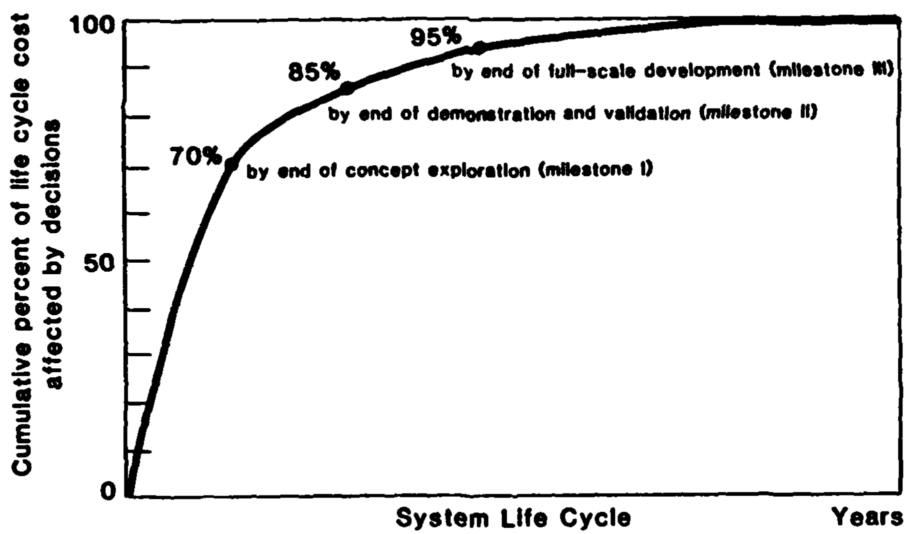
It is estimated that operational and support costs represent approximately 60% of a system's total life cycle costs. In addition, almost 85% of total life cycle costs is chargeable to the formulation of decisions made prior to the start of FSED. Therefore, much of the ultimate carrying or ownership costs for a given system are shaped by decisions made early during the concept exploration phase, even before advanced development and engineering development takes place. By emphasizing initial unit production costs without adequately considering long-term ownership costs, the opportunity to select available alternatives that could decrease any future logistics burden and reduce total life cycle costs was lost.

ACQUISITION CYCLE HISTORY

IMPACT OF DECISIONS AFFECTING LIFE CYCLE COST

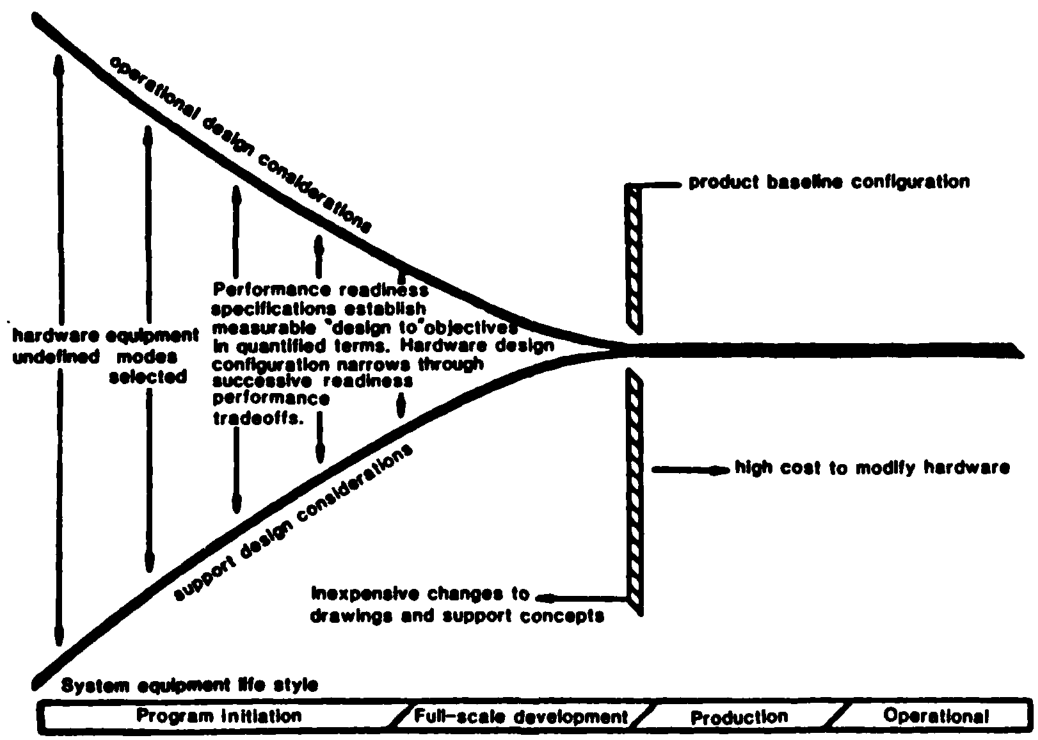


Source: *DSMC*, 1982

There is a strong relationship between operational design considerations and support design considerations. The longer the gap between these two is permitted to exist and the longer that support equipment remains undefined prior to the conclusion of FSED, the greater will be the cost of any future system design changes.

ACQUISITION CYCLE HISTORY

COST OF DESIGN CHANGES VERSUS SYSTEM LIFE CYCLE



Source: *DSMC*, 1982

OUTLINE

M1 System Description

Fault Detection and Isolation Subsystem

M1 Concept of Built-in Test Equipment/
Test Measurement and Diagnostic
Equipment (BITE/TMDE)

Acquisition Cycle History

Subsystem Performance

Summary and Conclusions

No data were collected on subsystem performance during DT/OT I because contractors were told in the 1973 RFP to not concern themselves with support equipment, test sets, etc., because they were not applicable to the prototype validation phase. Furthermore, analysis of the maintenance support concept was not possible because contractor personnel performed or advised on maintenance functions, and this limited the amount of operator-relevant maintenance data that could be gathered.

SUBSYSTEM PERFORMANCE

<u>DT/OT I</u>

- o No data available on BITE/TMDE or Technical Manuals.
- o Use of contractor maintenance support prevented adequate assessment of RAM.

During FSED and prior to DT/OT II, as many as seven separate test sets were developed to support maintenance at the organizational, DS, and GS levels. As a result of the DT/OT II experience, most of these test sets were found to be unreliable and were little used during the tests. The Fire Extinguisher and Organizational Test Sets were adequate, the TISTS was marginal, and the remaining four presented erroneous fault diagnoses. In a number of instances, test sets did not reveal actual faults, they were not consistent in fault isolation, and in some cases they even caused failure of other components. The accuracy rate of these test sets was less than 50%, and repair personnel were reluctant to use them. Once again there was heavy reliance on contractor backup support. In this role contractor personnel seldom used military test sets and troubleshooting procedures. They relied on their own test sets, software, and knowledge of the system.

During DT/OT II there was some limited evidence of a problem with the thresholds that were set for BITE. Draft equipment publications at all levels were deficient because troubleshooting procedures were difficult to follow and frequently contained errors. Furthermore, they did not meet the skill performance aid concept objectives because they were never properly validated.

MOS 45N (tank turret mechanic) and MOS 63C (tracked vehicle mechanic) were found to lack the skills required for maintaining the M1's sophisticated components. Additionally, the program of instruction for the training of crews and maintenance personnel was found to be inadequate.

SUBSYSTEM PERFORMANCE

<u>DT/OT II</u>

- BITE does not activate soon enough to prevent system damage
- Problem with automotive BITE false alarms.
- Total analysis of maintenance support concept not possible due to unreliability of test sets
- Maintenance manuals incomplete, difficult to use
- DS/GS-level training programs not fully developed to support system
- Excessive reliance on contractor troubleshooting knowledge and backup prevented adequate assessment of RAM

In DT/OT III there were some contradictory findings in BITE results and contradictions in the reporting of these results.

Three TMDE items were available for the test: STE/M1, TISTS, and DSESTS, but a discrete test of these test sets was not conducted. Test sets were used as required and usage data were collected and reported as part of the overall system evaluation. Of the three, only STE/M1 was ineffective. Use of TMDE was a trial-and-error on-the-job training learning experience. Special tools were judged to be excellent. Technical Manuals and maintenance instructions had to be updated so frequently that they could not be kept current.

MOS 45N (tank turret mechanic) and MOS 63C (tracked vehicle mechanic) were found to lack the skills required for maintaining sophisticated components of the M1 and seemed to have the most difficulty with troubleshooting. Prior experience with test sets helped as learning improved with use.

SUBSYSTEM PERFORMANCE

DT/OT III

- o BITE alarms still problematic
  - -- BITE in turret satisfactory
  - -- BITE in hull a source of problems
- o TMDE available for training had limited functional capacity
  - -- *STE/M1 unreliable*
  - -- DSESTS testing limited but reasonably reliable
  - -- TSTS not available for testing
- o Maintenance manuals still not adequate
  - -- Required frequent updates
  - -- Many inaccuracies
- o Maintenance personnel unable to identify basic faults or malfunctions

Subsystem Performance: Overview

For the most part, BITE currently works as well as its design allows.

Software logic errors and hardware problems continue to plague the STE/M1. Lack of confidence in this test set still prevails, as evidenced by its infrequent use and reliance upon alternative test procedures.

The TSTS is not yet in production.

Maintenance manuals have shown some improvements since DT/OT III testing.

SUBSYSTEM PERFORMANCE

Current Status

- o BITE false alarm rate improved
- o Continued lack of confidence in STE/M1
- o Thermal System Test Set still not available--"Hot Mock-up" only
- o Manuals show improvement in some areas

In the OT III independent evaluation report (IER), overall BITE was deemed to be satisfactory. This conclusion is based on the Fort Hood, Texas, data reported in the test report prepared there. However, there appears to be a tenuous relationship between statements regarding BITE from the Fort Knox, Kentucky, test report and the originally unpublished Fort Hood data (which were both seemingly negative) and the positive OT III IER evaluation.

The DT III IER position is that unspecified BITE in the turret is satisfactory and specified BITE in the hull is unsatisfactory. The latter was caused by hardware problems and was being addressed in modifications. Despite BITE's "appearance" of functioning properly, no quantified, rigorous data were presented upon which to evaluate BITE performance.

No data were available on BITE from OT I, DT II Desert Test, and the comparability tests. During the Product Validation Test (PVT), some unquantified BITE problems were discussed that dealt with automotive BITE false alarms and BITE not activating early enough to prevent M1 system damages. In all cases it was not clear what criteria were being used to assess BITE.

BITE PERFORMANCE EVALUATED

OT II

Events	Correct	Failed to Light	Wrong Light	False Alarms
123	87%	6.5%	6.5%	0

DT II

Unquantified automotive BITE false alarms.

BITE lights too late to prevent damage.

OT III

	Correct	False Alarms
Ft. Hood	89%	
Ft. Knox	58%	18%

Conclusion:

BITE satisfactory (IER, p. 70)

Data not reported:*

Faults	BITE Signaled	BITE Missed
455	62%	38%

BITE Signals	Correct	False Alarms
337	84%	16%

Authentic Signals	Correct Isolation	Incorrect Isolation
311	71	29

*Collected at Fort Hood during OT III and reported in *Evaluation of Abrams MBT Maintenance Personnel*, USAOC&S, June 1981.

DT III

Unquantified problems indicated in BITE in hull
- o engine false alarms
- o fuel faults
- o transmission oil clog

BITE in turret satisfactory.

Meaningful performance criteria were never specified for BITE, and no BITE performance was reported from OTI. This would have been the most cost effective test from which to base the correction of system faults. In subsequent testing all potential sources of BITE error were not tested and, with the exception of several sensor problems and alterations of signal thresholds, the causes of BITE errors were not reported.

BITE was tested in a manner that de-emphasized soldiers' use of the equipment, making realistic evaluations of its battlefield utility difficult. Human factors measures of BITE were not taken and linked to soldier-BITE performance trials, making causal diagnosis of BITE errors fragmentary.

Army decisionmakers have not been given meaningful information to judge the realistic effectiveness of BITE in the hands of soldiers or to make recommendations for its improvement.

SUBSYSTEM PERFORMANCE

<u>Inadequacies in Subsystem Performance Test and Evaluation</u>

<u>BITE</u>

- o Never operationally defined
- o No performance criteria established
- o Limited interest in evaluating BITE early on
- o Contradictory data
- o Limitations in test
- o Human performance interactions ignored

Before consolidating test sets, four of the seven in use during DT/OT II test and evaluation were reported to be inadequate and unreliable. Unquantified data indicated that they did not reveal actual faults, they were inconsistent in fault isolation, and they sometimes caused other components to fail.

After consolidating test sets from seven to three, causes of poor reliability were said to include software/hardware errors, manual/technical publication errors, procedural errors, and insufficient test set functional capability. Almost all of the formalized DT/OT and comparison tests attribute test set problems to the causes listed above and provide this information in general, unquantified form.

Although STE hardware/software and manuals during DT III were identical to those in the DT III M (Maintenance Evaluation) Test, the higher reliability percentage of .82 found in the latter test may be due to the difference in test method. The DT III M test utilized a procedure of fault insertions. It is unlikely that the full range of faults associated with STE troubleshooting problems was inserted. Further, the method of fault insertion may have led to an increase in the probability of troubleshooting success. The same comments also apply to DSESTS results.

The OT III IER states that DSESTS is inadequate for support maintenance. It also states that DSESTS and TISTS were generally effective. The relationship between the Fort Knox data and this latter statement is unclear.

TEST SET PERFORMANCE

	OT I	OT II	DT II PQT	DT II DSRT	OT III Knox/Hood	DT III	DT III M-EVAL	PVT	COMP 5/83	COMP 6/83	COMP 7/83
Preconsolidation	Not mentioned in IER. Not available for testing.	Test sets less than 50% reliable	Test sets not reliable (unquantified). Said to have met criterion (p. 210, PQT)	Test sets not reliable							
STE troubleshooting (percent correct)					25% 68%	42%	82%[1]	44%	25%	50%	25%
DSESTS troubleshooting (percent correct)					58%[2] 95%	61.5%	97%	73%		75%	100%[4]
TISTS troubleshooting (percent correct)					100%[3] 84%[3]			OK			

[1] Include fault insertions, may not be fully representative of true capability.

[2] OT III IER states that DSESTS is inadequate for support maintenance (p. 71).

[3] Hot mock-up is basis for all reported evaluations.

[4] Based on one trial of DSESTS use.

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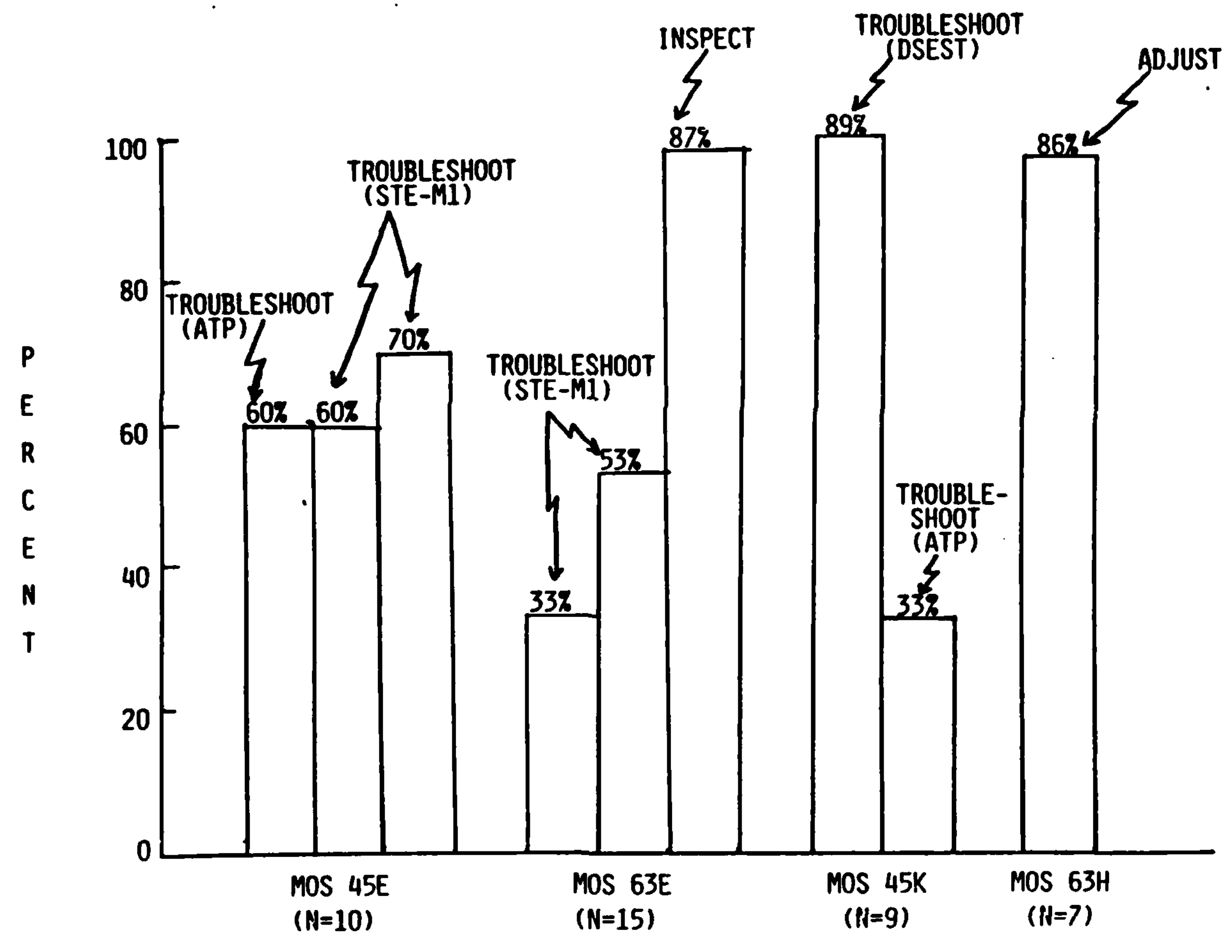
[2] OT III IER states that DSESTS is inadequate for support maintenance (p. 71)
[3] Hot mock-up is basis for all reported evaluations
[4] Based on one trial of DSESTS use

Subsystem Performance: Overview

A hands-on performance test covering nine different tasks was administered to 41 soldiers who had received M1 training. The criterion performance score of 90% was not achieved on any task. Performance scores ranged from a low of 33% to a high of 70% on tasks involving the use of STE/M1 and alternate test procedures (ATP).

HANDS-ON PERFORMANCE TEST (POST OT III FORT HOOD)



Source: *USAOC&S*, June 1981.

Subsystem Performance: Overview

The chart below lists the quantifiable sources of unreliability associated with STE/M1 and DSESTS found during DT III testing.

SOURCES OF UNRELIABILITY ASSOCIATED WITH TEST SETS

STE: 31 unsuccessful trials

Types of Reliability Problem Causes	Number of Trials Affected	Percentage of Trials Affected Entirely or in Part (do not sum to 100%)
Hardware/software	10+part of 2	38.7%
Procedures	3+part of 3	19.4%
Manuals	1+part of 2	9.7%
Function unavailable	2	6.5%
Unknown	12	38.7%

DSESTS: 5 unsuccessful trials

Types of Reliability Problem Causes	Number of Trials Affected	Percentage of Trials Affected Entirely or in Part (do not sum to 100%)
Hardware/software	1+part of 2	60%
Function unavailable	2	40%
Unknown	2	40%

Source: *DT III IER.*

Statements made in DT/OT reports could be construed as indicating that personnel related problems were somehow thought to be associated with the inadequacy of test set use, and that these shortcomings could be remedied through personnel changes. Such causes of test-set unreliability have been identified as insufficient numbers of personnel, inexperienced personnel, and/or incorrect type of personnel. However, there are no quantifiable test data to demonstrate the accuracy of these inferences.

TEST SET PERFORMANCE EXACERBATED BY PERSONNEL

OT III	Calls for change of MOS 34G to 35B, and the addition of seven additional maintenance personnel at the direct support unit level-- 2 Tank Turret Mechanics 45 E10 (E3) 3 Tracked Vehicle Mech 63 E10 (E3) 1 Tracked Vehicle Mech 63 E10 (E4) 1 Armament Maint Officer 421 WO. (OT III IER, pp. 57-58) "Maintenance personnel did not demonstrate a basic understanding of how the various subsystems function and interact." (Fort Knox OT III Test Report, p. I135)
DT III	Calls for the establishment of special diagnostic teams ". . . whose sole purpose would be to aid in the fault isolation of complex failures." Further, it suggests the addition of: 1 Turret system Senior Sgt. (DT III IER, p. 283)
PQT (partial)	". . . Skills, experience and aptitudes provided by current and/or projected TOE and MOS structure are not adequate for . . . maintenance of the XM1 tanks." . . . "This is especially so since the test sets are totally unreliable." MOS types could not diagnose troubles in various components, using schematics and standard equipment. (Partial PQT, pp. 217-19)

The chart below is a sampling of incidents reflecting field usage of M1 diagnostic aids, recorded under the Sample Data Collection Program from January 1982 through February 1984.

UNSCHEDULED MAINTENANCE INCIDENTS

Diagnostic Aids	Number of Incidents		
	USAREUR (16 tanks)	Fort Hood (17 tanks)	Total (33 tanks)
STE/M1	17 (2%)	26 (4%)	43 (3%)
DSESTS	2 (<1%)	2 (<1%)	4 (<1%)
ATP	154 (18%)	44 (7%)	198 (13%)
None	310 (36%)	419 (63%)	729 (48%)
Other Aids	372 (44%)	169 (26%)	541 (36%)
Total	855	660	1,515

Source: Sample Data Collection Program.

The M1 STE/M1, DSESTS, and the alternate test procedure require more maintenance time per incident than the <u>none</u> or <u>other aid</u> category. <u>Other aid</u> category includes non-M1 specific diagnostic methods and aids, e.g., multi meter, trial and error, and other general diagnostic supports.

UNSCHEDULED MAINTENANCE TIME

Diagnostic Aids	Maintenance Clock Hours					
	USAREUR (16 tanks)		Fort Hood (17 tanks)		Total (33 tanks)	
	Total	$\bar{X}$*	Total	$\bar{X}$*	Total	$\bar{X}$*
STE/M1	61.0	3.6	198.0	7.6	259.0	6.0
DSESTS	10.5	5.2	14.5	7.2	25.0	6.2
ATP	407.4	2.6	351.3	8.0	758.7	3.8
None	593.6	1.9	1,292.6	3.1	1,886.2	2.6
Other aids	933.1	2.5	782.6	4.6	1,715.7	3.2

*Average per incident.

Source: Sample Data Collection Program.

The STE/M1 and ATP, the primary diagnostic aids for use at crew/organizational level, are used infrequently in the field for fault diagnosis. When used, they continue to be a significant source of the problems associated with troubleshooting the M1.

STE/M1 AND ATP ARE HIGH DRIVERS

- The STE/M1 is seldom used (3%) to help troubleshoot.
- The ATP is used somewhat more frequently (13%) to help troubleshoot.
- When the STE/M1 is used, it requires--on the average--6 clock hours per unscheduled maintenance incident, i.e., 2 hours greater than the 4 clock hour requirement.
- When the ATP is used, it requires--on the average--3.8 clock hours, which is just within the time requirement.

<u>Source</u>: Sample Data Collection Program.

Because of the poor performance of the test sets, personnel had no confidence in them, even after software improvements had been made.

SUBSYSTEM PERFORMANCE

Reasons for Continuing Lack of Confidence in STE/M1

- High frequency of incorrect diagnosis throughout its history
- Poor correspondence between STE/M1 procedures and troubleshooting manuals
- Difficulty in connecting to tank
- Difficulty in transporting (size, unwieldy)
- High occurrence of cable connector and adaptor damage
- Inability to self-test cables and adaptors
- Technicians receive insufficient training in its use
- Fault isolation procedure limited (isolates only one problem at a time)
- Testing with STE/M1 is very time-consuming.
- Logic errors still persist in software design
- Problems in detecting transient malfunctions
- No source of power for testing independent of tank

Source: DT/OT testing, interviews, Sample Data Collection Program.

Test-set requirements and performance criteria were never established prior to DT/OT I. Only a physical teardown/maintenance evaluation performed to provide data for estimating annual maintenance manhours showed that test sets posed potentially serious problems. The actual level of test set-problems could not be known due to the use of contractor maintenance personnel and lack of worst-case conditions in testing. In addition, the effectiveness of training could not be fully understood because of frequent program changes and the ineffectiveness of hardware/software and manuals.

Test-set problems were caused in part by hardware/software errors, procedural errors, errors in manuals, and limited functional capability. Nonapplication of human factors test methodology precluded complete understanding of potential causes. A significant percentage of test-set problem causes was not determined. They may or may not have had roots in human factors. TSTS was never actually evaluated.

Army decisionmakers have been given enough information to determine that there were significant problems with some ATE test sets (particularly STE/M1). They have been given information about the effects of those problems and some of their causes. The nature of the testing of these test sets was such that the decisionmakers were not given information about the potential magnitude of test-set problems and all possible causes of and solutions to these problems.

SUBSYSTEM PERFORMANCE

Inadequacies in Subsystem Performance Test and Evaluation

Automatic Test Equipment

- o Test-set requirements effectively ignored during DT/OT I
- o No performance criteria established
- o Dependence upon contractor personnel
- o Training on usage not validated
- o Indeterminate cause of problems
- o Thermal system test set never really evaluated

M1 TMs were also found to be high drivers. TMs were reported to be bulky, poorly organized, and laden with errors. Data from INFONET revealed that maintenance personnel at Fort Knox considered the manuals inadequate 94% of the time they were used. Manuals were referred to only 30% of the time that they could have been used.

EVALUATION OF TECHNICAL MANUALS DURING OT III (FORT KNOX)

User	Times Used	Procedures Followed	Adequate
Crew/operator	7	57%	29%
Organizational	11	73%	18%
Direct support	19	84%	11%
Depot	268	99%	5%
	305	96%	6%

Data collected during formalized testing and evaluation show evidence of serious RAM problems with M1. Downtime is an important function of both system reliability and maintainability and has an impact on system availability. Soldier maintenance, complicated by difficulties with the use of test sets, exacerbates the problem.

SUBSYSTEM PERFORMANCE

Impact on RAM

- Evidence of serious RAM problems with M1
- Increased downtime exacerbates the problem
- Soldier maintenance seen as a contributor
- Difficulties in use of test sets contribute to excessive diagnosis/troubleshooting times

Subsystem Performance: RAM

System reliability was consistently below the MN criterion of 101 mean miles before failure. In DT III, when adjusted findings (99 MMBF) nearly approach the criterion, Army Materiel Systems Analysis Agency (AMSAA) indicated a lack of confidence in the results because of the omission of secondary sources of error.

M1 RELIABILITY

	MN CRIT	DT II/ OT II MAV	OT I	OT II	DT II PQT	DT II DRST	DT III	DT III (ADJ)	OT III	OT III (ADJ)	PVT	COMP 2/83
System (MMBF)	101	90	--	77.8	58.6	17.85	75	99	130	161	73.5	66.8
Mission	320	222	--	104.3	125.8		251	336	304	362	24.0	93.9

Operational measures of effectiveness (which include soldier error) result in significantly more measured downtime and lower reliability than traditional measures. One such measure, mean miles between essential maintenance demands (MMBEMD), takes into account secondary sources (such as soldier errors of omission) during primary source maintenance. When this measure is applied, mean mileage attained drops considerably.

M1 RELIABILITY

	MN CRIT (MMBF)	DT III (ADJ)	DT III MMBEMD*	OT III (ADJ)	OT III MMBEMD*	
					FORT KNOX	FORT HOOD
System	101	99	43	161	47	43

*Includes accidents, maintenance errors, and test item abuse

A comparison between two M1 tanks maintained by civilians and one maintained by soldiers indicated that soldier maintenance resulted in lowered reliability. Since the soldier-maintained tank was aided by civilian support, the real difference between soldier- and civilian-maintained tanks conceivably could be greater than measured.

DT III INDEPENDENT EVALUATION REPORT (AMSAA)

	System (MMBF)	Mission (MMBF)
Civilian-maintained tank	95	387
Civilian-maintained tank	87	228
Soldier-maintained tank	51	167
Difference	56%	54%

Subsystem Performance: RAM

Despite the fact that no MN requirement was stated for availability, documented measures of achieved availability (Aa) for the M1 fall short of the Aa of .88 recorded for the M60A1.

$$\text{Aa} = \frac{\text{Operating time}}{\text{Operating time} + \text{Total preventive maintenance time} + \text{Total corrective maintenance time}}$$

M1 AVAILABILITY (A_o)

	DT II	DT II		OT III				COMP	COMP	COMP	COMP
OT I	PQT	DSRT	OT II	Knox	Hood	DT III	PVT	2/83	5/83	6/83	7/83
--	.59	.28	.568	.48	.724	--	.62	.62	.74	.82	.67

M60A1 (A_o) = .88

The fact that a significant percentage of maintenance downtime is spent in diagnosis is seen as a major contributor to total downtime. Therefore, the more unreliable the system, the more important becomes the question of how soldiers can effectively maintain it using diagnostic aids.

DIAGNOSIS TIME CONTRIBUTES EXCESSIVELY TO MAINTENANCE TIME

OT II	DT III	OT III Fort Hood	DT II DSRT
M1 = 20.7% of maint. time	M1 = 26% of maint. clock hrs. 28% of man hrs. seen as main driver of low MMBEMD	Large (unquantified) percentage of down-time spent in diagnosis	Excessive downtime due to difficulties in test set use
M60A1 = 7% of maint. time			

The large number of scheduled organizational manhours in OT III should be noted. This may or may not have had an effect on reducing the number of unscheduled maintenance manhours (particularly at the DS level), but it may have some implications for the number of personnel required at the organizational level.

RELATIONSHIP BETWEEN MAINTENANCE EVENTS AND TIME CRITERIA

	MN* CRIT	DT II/ OT II MAV	DT II PQT	DT II DSRT	OT II**	DT III	OT III	PVT	COMP 2/83	COMP 5/83	COMP 6/83	COMP 7/83
SCHEDULED												
CREW												
Clock hours	.75	.88		--	--	--	--	--	--	--	--	--
Man hours	3.00	3.53		--	--	--	--	--	--	--	--	--
ORG.												
Clock hours	36.0	42.0	17.5	--	25.7	27.0	37.2	28.8	--	--	--	--
Man hours	64.0	75.0	42.0	--	62.0	43.0	103.0	46.8	--	--	--	--
UNSCHEDULED												
ORG.												
Clock hours	4.0	4.7	4.6	--	81.0%	2.9	5.7	2.9	5.2	.17	1.5	3.5
Man hours	8.0	9.4	7.7	--	79.0%	4.3	6.2	4.3	9.3	2.90	1.7	7.0
DS												
Clock hours	12.0	14.0	13.9	--	95.0%	8.5	7.5	8.5	--	--	--	--
Man hours	22.0	26.0	33.4	--	97.0%	12.7	9.1	12.7	--	--	--	--

*Criterion required meeting these times with 90% frequency

**Data for unscheduled maintenance events reported in percentages in *OT II IER*, pp. 181-185

Subsystem Performance: RAM

The chart below reveals that USAREUR meets the requirement at the clock-hour level (90%) and almost satisfies it at the manhour level (89%).

Fort Hood indicates a shortfall of 15% below the criterion for clock hours and a shortfall of 14% below the manhour criterion.

Overall, the combined clock-hour and manhour maintenance times indicate a shortfall of 6% and 7%, respectively, to the criterion.

UNSCHEDULED MAINTENANCE AT CREW/ORGANIZATIONAL LEVEL

<u>Requirement</u>: Unscheduled maintenance incidents should require less than 4 clock hours and less than 8 man hours 90% of the time.

	USAREUR	Fort Hood	Total
<u>Clock hours</u>			
Incidents $\geqq$ 4 hours	84 (10%)	153 (25%)	237 (16%)
Total incidents	836 (100%)	620 (100%)	1,456 (100%)
<u>Man hours</u>			
Incidents $\geqq$ 8 hours	94 (11%)	147 (24%)	241 (17%)
Total incidents	836 (100%)	620 (100%)	1,456 (100%)

Lack of an integrated systems approach, inadequate testing of logistics supportability, and inappropriate emphasis on HMPT concerns have made it difficult for the Army to accurately assess not only RAM but also maintainer personnel performance capabilities. No effective measures of realistic operational supportability exist.

IMPACT OF HUMAN FACTORS, MANPOWER, PERSONNEL, AND TRAINING

General

- Early requirements documents neglected maintainer performance
- Funding constraints prevented proper Integrated Logistics System effort
- Compressed schedule adversely affected human factors, manpower, personnel, and training development
- Lack of total systems approach
- Human performance criteria not well established
- Inadequate testing for logistics supportability

Almost a complete set of maintenance diagnostic test-set simulators/trainers (design development effort) was invalidated by a complete revision of the test sets when they did not perform well in DT/OT II.

Because of slippage, maintenance/troubleshooting simulators (for use by DS/GS) were not delivered in time to support OT III training.

The recently acquired maintenance trainer (late 1983), turret training simulator, and panel trainer (both obtained early 1984) are just now being fully integrated into the training system.

IMPACT ON HUMAN FACTORS, MANPOWER, PERSONNEL, AND TRAINING

Training Device Development

- Initial maintenance trainers invalidated
- Maintenance simulators not available to support OT III training
- Simulators just now being integrated into training system

As early as DT/OT II, limited evaluation indicated that the skills, experience, and aptitudes provided by current and/or projected table of organization and equipment (TOE) and MOS structure would not be adequate for maintenance of the M1. This was particularly true of the tank turret mechanic (MOS 45N) and tracked vehicle mechanic (MOS 63C), who had difficulty in diagnosing troubles in various components using schematics and standard equipment. Consequently, two system-specific organizational MOS with planned system-specific training were created. These were MOS 63E, M1 tank systems mechanic, and MOS 45E, M1 tank turret mechanic. Similarly, at the DS/GS level 5 MOS were given an M1 additional skill identifier (ASI).

It seems that even as late as DT/OT III, M1 personnel were still ill prepared to perform fault diagnosis and detection tasks. In many cases, maintenance personnel did not have a basic understanding of how the various subsystems function and interact. They were not able to identify the basic fault or malfunction that brought about the requirement for maintenance. Personnel had limited experience with, and were reluctant to use, technical manuals. Because the test sets had performed so poorly, personnel had no confidence in them even after software improvements had been made.

IMPACT ON HUMAN FACTORS, MANPOWER, PERSONNEL, AND TRAINING

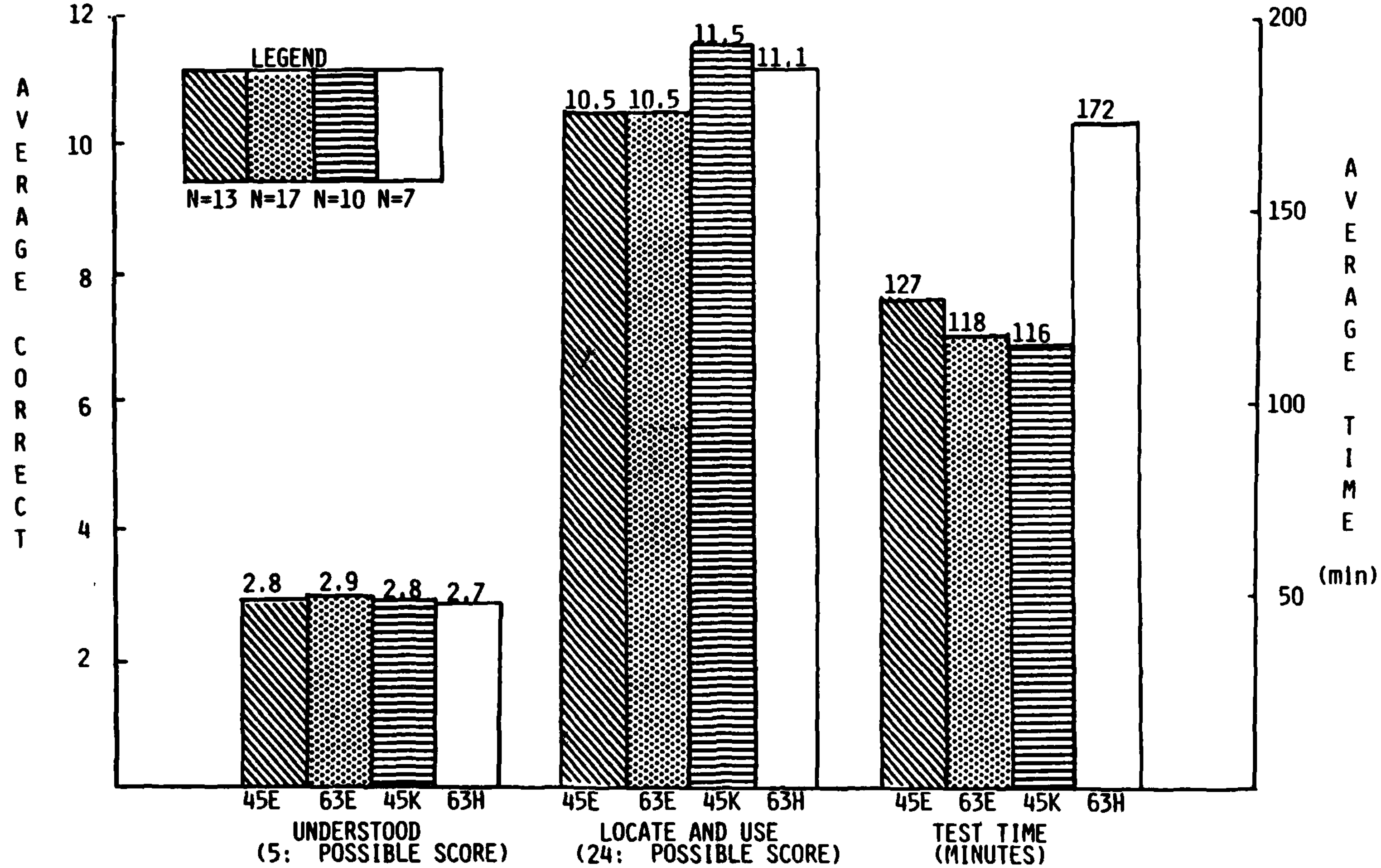
<u>Maintainer Troubleshooting Deficiencies</u>

- o Limited understanding of system functions
- o Inability to accurately identify basic fault
- o Limited facility in using Technical Manuals
- o Lack of confidence in test equipment

Subsystem Performance: HMPT

A written and hands-on test involving the understanding and ability to use M1 technical manuals was administered to soldiers in each of four MOS. For the understood portion, less than two-thirds of the questions were correctly answered. On the locate and use portion, less than 50% of the items were scored as being correct. The 63H MOS required considerably longer time to complete the test.

TECHNICAL MANUAL WRITTEN TEST (POST OT III FORT HOOD)



Source: *USAOC&S*, June 1981.

During an M1 training evaluation conducted by the USAOC&S in November 1979, a diagnostic pretest given to OT III player personnel revealed significant shortfalls in skills and knowledge associated with troubleshooting and diagnostics using TMDE.

Utilization of alternate test procedures was also found to be inadequate. These procedures, which are used sometimes in lieu of or to supplement ATE, require some understanding of the basic principles and theory of hydraulics, mechanics, and electricity. Unfortunately, SPA TMs do not contain this information and, furthermore, they deemphasize theory in training programs.

IMPACT ON HUMAN FACTORS, MANPOWER, PERSONNEL, AND TRAINING

Precourse Diagnostic Testing

MOS	Number Tested		Number of Personnel Marginal, Weak, or Failed
Fire Control Computer Repairman (34G)	9	Soldiering techniques	2
		Use of oscilloscope	2
		Laser theory	4
Tank Turret Repairman (45K)	19	Troubleshoot hydraulic system	10
		Use of multimeter	7
Track Vehicle Repairman (63H)	42	Use of:	
		STE/ICE	42*
		Multimeter	32
		Special tools	16
		Wiring diagrams	21
		Theory on:	
		Suspension	38
		Transmission	20
		Planetary gears	28
		Hydraulics	24
Fuel and Electrical System Repairman (63G)	9	Use of:	
		Multimeter	8
		STE/ICE	9*
		Wiring diagrams	3
		Test stand	8

*STE/ICE unavailable for practice

Source: *M1 Training Evaluation--USAOC&S*, June 1981.

In a training effectiveness analysis (TEA) of new equipment training (NET) for transition M60A1 operators and maintainers to become M1 tank-qualified, personnel were seen to lack confidence in their ability to apply troubleshooting skills.

The MOS 45E training program indicated below-criterion performance in all but one task and was considered ineffective.

Limited weaknesses were shown in the tracked vehicle mechanics' program. Only one task was not adequately performed by at least 80% of those tested--troubleshooting using STE/M1 test sets.

IMPACT ON HUMAN FACTORS, MANPOWER, PERSONNEL, AND TRAINING

Soldier Confidence in Troubleshooting Skills

Crewman (MOS 19K)

- o Lacked confidence in ability to troubleshoot Fire Control System

Turret Mechanic (MOS 45E)

- o Uncertain of ability to troubleshoot hydraulic system

Tracked Vehicle Mechanic (MOS 63E)

- o Troubleshooting ability judged less than adequate
  - -- Troubleshoot engine using STE/M1
  - -- Troubleshoot transmission using STE/M1
  - -- Troubleshoot Vehicle Fuel System using ATP

Source: *TRASANA M1 Training Effectiveness Analysis*, September 1981.

Subsequent to OT III, recommendations were made to significantly change training Programs of Instruction (POI) for M1 mechanics. For MOS 63E (hull mechanic) it was recommended that the length of modules dealing with troubleshooting and the use of diagnostic aids be increased by 185% (from 24 to 68.5 hours). It was also suggested that the course length for MOS 45E (turret mechanic) be increased by 85%. The module having the largest training time (40 hours) in this POI is troubleshooting using the STE/M1.

M1 MECHANICS TRAINING IS A HIGH DRIVER

- Emphasis in 45E/63E training is on troubleshooting tasks and use of diagnostic aids
- Increased emphasis on theory
- Diagnostic training simulators and devices are currently being incorporated into 45E/63E training

The recommended revision of the POI for MOS 63E was based upon the M1 training effectiveness analysis conducted at Fort Hood. The two tasks denoted as critical deficiencies are troubleshooting using the STE/M1 and using ATP.

ORGANIZATIONAL MAINTENANCE TRAINING EVALUATION

OT III Fort Hood (MOS 63E)

Tasks	Recommended POI Changes From	To	Summary of Changes
Remove and install (R/I) ballistic skirts	Delete workbook		Delete 3 workbooks
R/I Roadwheel arm and rotary shock assembly	Delete workbook		Delete 2 tasks
R/I hull electrical system components	30.0	19.5 hours	Add 3 tasks
R/I fire extinguisher system components	7.5	13.5 hours	R/I tasks: Decrease
R/I air induction system components	7.0	4.5 hours	POI time 89.5
R/I power plant	8.0	9.0 hours	66.5 hours (26%
R/I oil cooling system components	19.0	13.0 hours	decrease)
R/I transmission valve bodies and solenoids	18.0	7.0 hours	Adjust & ground hop
Adjust transmission parking brake	3.0	4.0 hours	tasks: Increase POI
Ground hop the power pack	2.4	4.0 hours	time 5.4 8 hours
Set up procedures for STE/M1 test set	Delete workbook		(48% increase)
Troubleshoot using the STE/M1 test set*	12.0	27.5 hours	Troubleshooting
Alternate troubleshooting procedures*	12.0	25.0 hours	tasks & diagnostic
Adjust transmission steering	Delete task		aids: Increase POI
R/I fuel pump	Delete task		time 24 68.5
Use of troubleshooting manuals	0.0	8.0 hours	(185% increase)
Use of maintenance manuals	0.0	8.0 hours	
Drive the M1 tank	0.0	8.0 hours	

*Critical deficiencies.

A similar analysis for MOS 45E POI revealed that replacing hydraulic components and troubleshooting using the STE/M1 were the most critical deficiencies. The increase from 24 to 40 hours on the latter module represents 33% of the total recommended increase in course length.

ORGANIZATIONAL MAINTENANCE TRAINING EVALUATION

OT III Fort Hood (MOS 45E)

Tasks	Recommended POI Changes From	Recommended POI Changes To	Summary of Changes
Equipment manuals	3.0	8 hours	Recommended 55% increase in course length.
Turret orientation	3.0	4 hours	
Maintain ballistic computer	10.0	12 hours	
Maintain turret electrical system	8.0	8 hours	
Maintain hydraulic system	7.0	7 hours	
Replace hydraulic components*	9.5	13 hours	
Maintain armament system	4.0	15 hours	
Maintain fire control system	20.0	30 hours	
Troubleshoot using the STE/M1*	24.0	40 hours	
Total	88.5	137	

*Major deficiencies.

There has been a series of perturbations in the M1 training program since OT III. The chart below shows the nature and extent of module changes by maintenance function and the average number of hours devoted to each. It also demonstrates that the effectiveness of training is not fully understood because of frequent program changes and the seemingly ineffective nature of fault detection hardware/software and procedures.

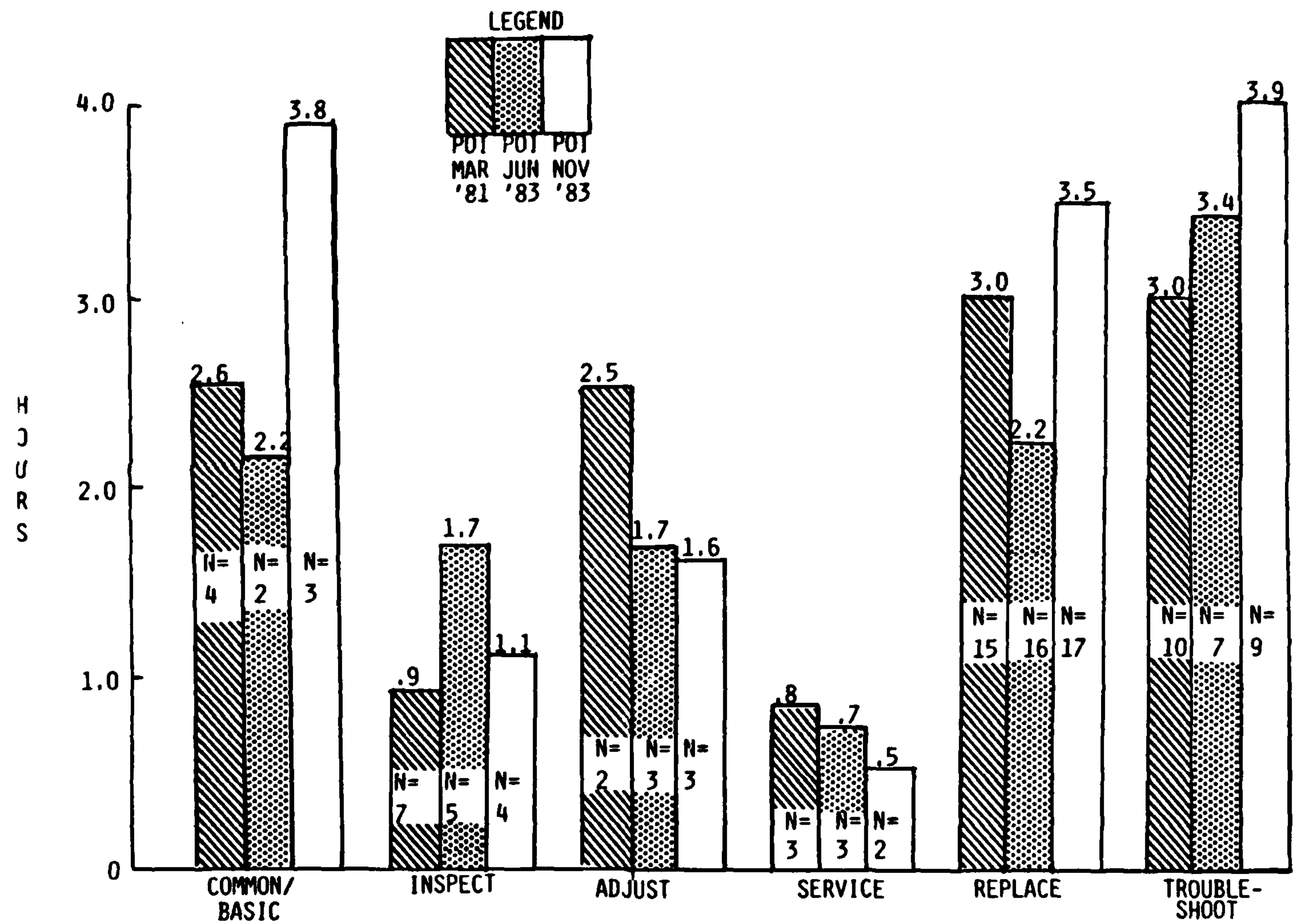


FIG: *Changes in number of Training Modules (N=) per Maintenance function and average number of hours devoted to each module.*

Organizational mechanics' mental aptitudes are a high driver. The M1 tank is a technologically sophisticated weapons system requiring complex troubleshooting skills and diagnostic aids, yet the organizational mechanics (45E, 63E) are lower in mental aptitude (mental category) than either Army-wide soldiers or MOS 19K M1 tank crewmen.

MENTAL CATEGORY MOS VS. ARMY-WIDE

	I-IIIA	IIIB-IV
MOS 19K (M1 tank crewman)	51%	47%
MOS 45E (turret mechanics)	46%	54%
MOS 63E (hull mechanics)	41%	59%
Army-wide	53%	47%

Source: *Enlisted Master File*, March 1984.

The data indicate that a greater percentage of 1983 accessions fall within mental categories I, II, and IIIA than do soldiers assigned to either MOS 45E or to MOS 63E. Sixty-one percent of the 1983 accessions fall between mental categories I and IIIA. This is in contrast to 46% for MOS 45E and 42% for MOS 63E.

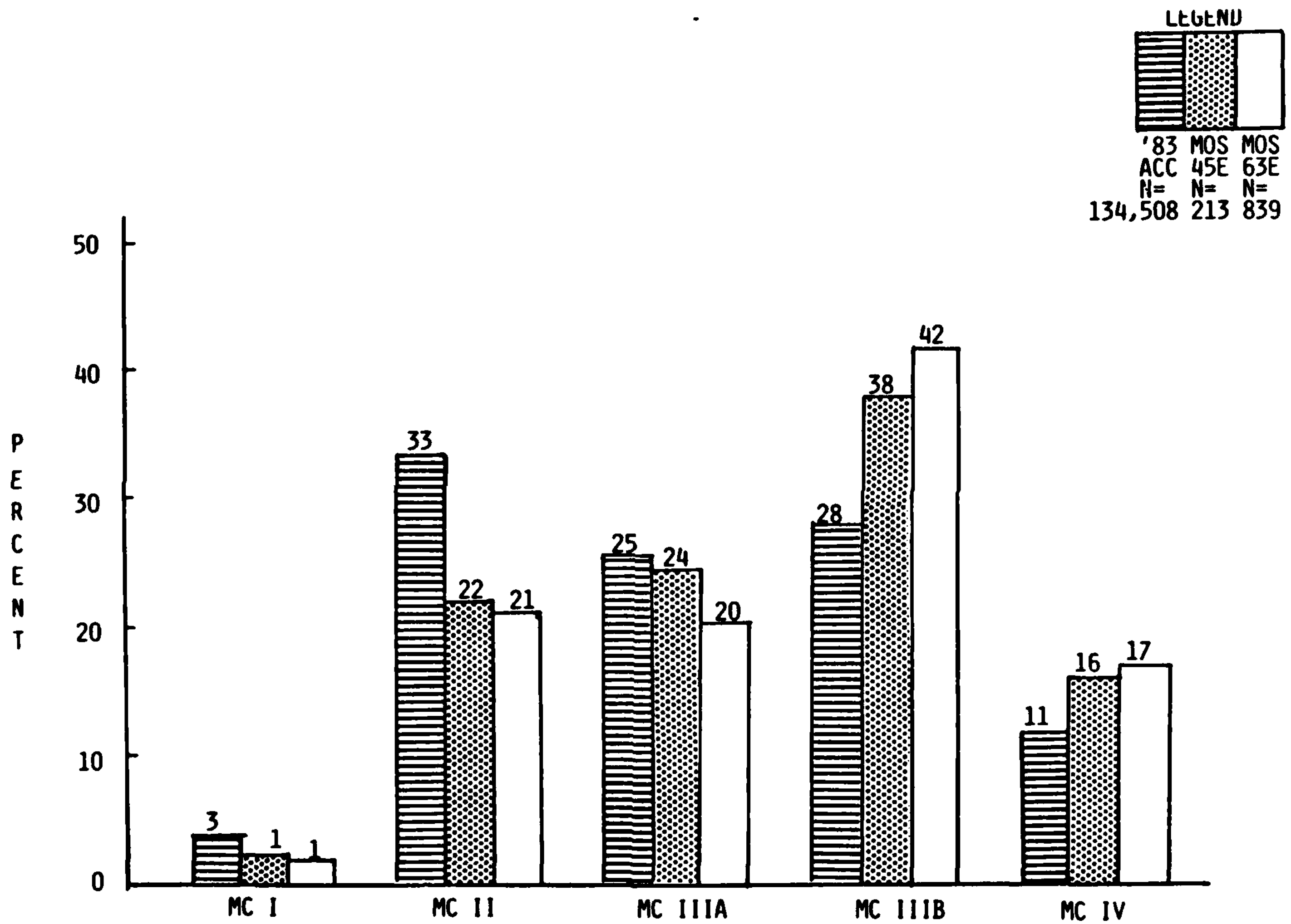


FIG: 1983 ACCESSIONS VS. M1 ORGANIZATIONAL LEVEL MECHANICS

A greater percentage of 1983 accessions (61%) falls within mental categories I-IIIA than do soldiers assigned to M1 DS/GS level maintenance, i.e., MOS 45K, MOS 63G, MOS 63H, and MOS 41C. With the exception of MOS 45K, the other DS/GS level mechanics have about the same percentage of soldiers in mental categories IIIB-IV as the 1983 accessions have within mental categories I-IIIA.

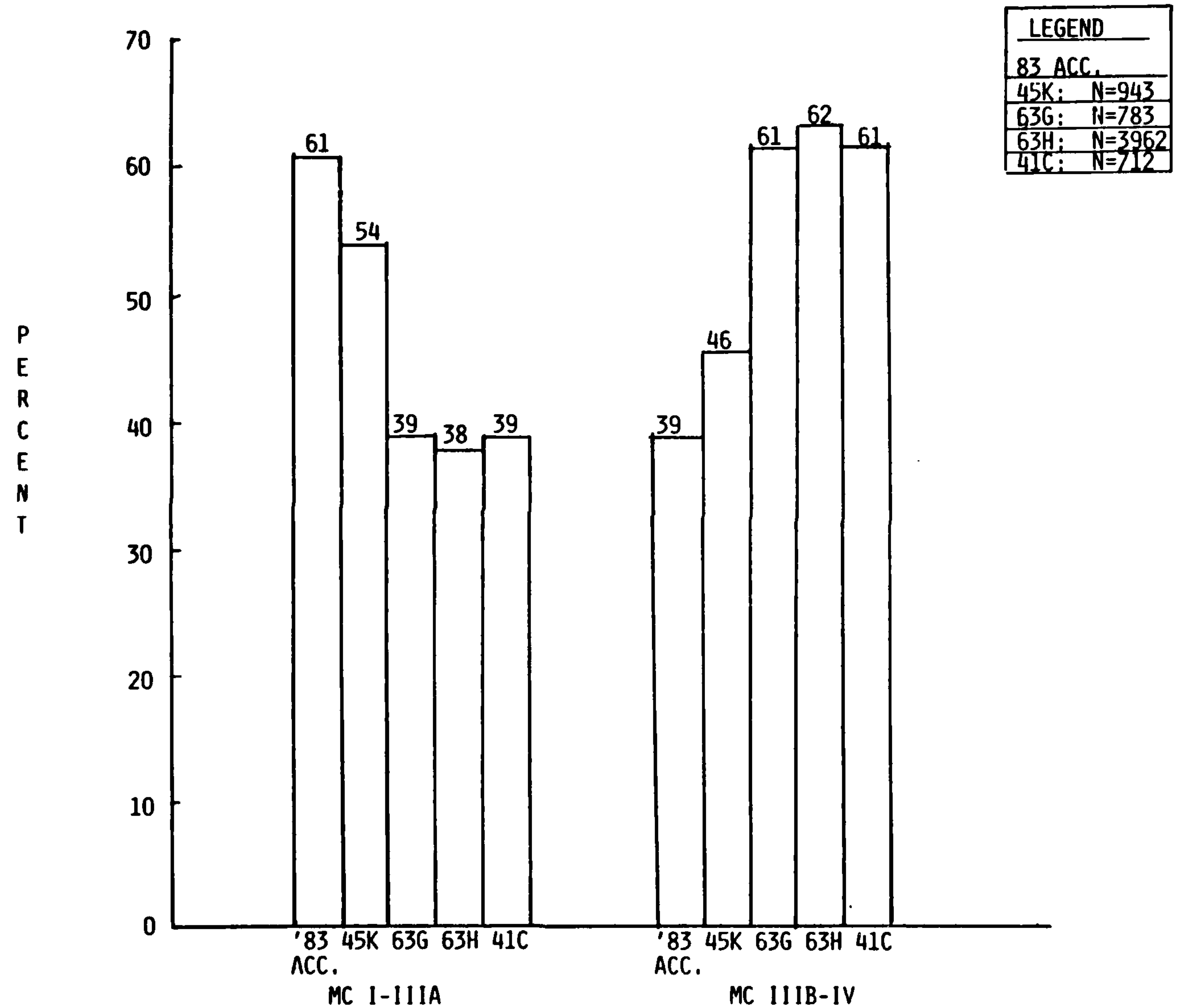


FIG: 1983 ACCESSIONS VS. MI DS/GS LEVEL MECHANICS

OUTLINE

M1 System Description

Fault Detection and Isolation Subsystem

M1 Concept of Built-in Test Equipment/
Test Measurement and Diagnostic
Equipment (BITE/TMDE)

Acquisition Cycle History

Subsystem Performance

Summary and Conclusions

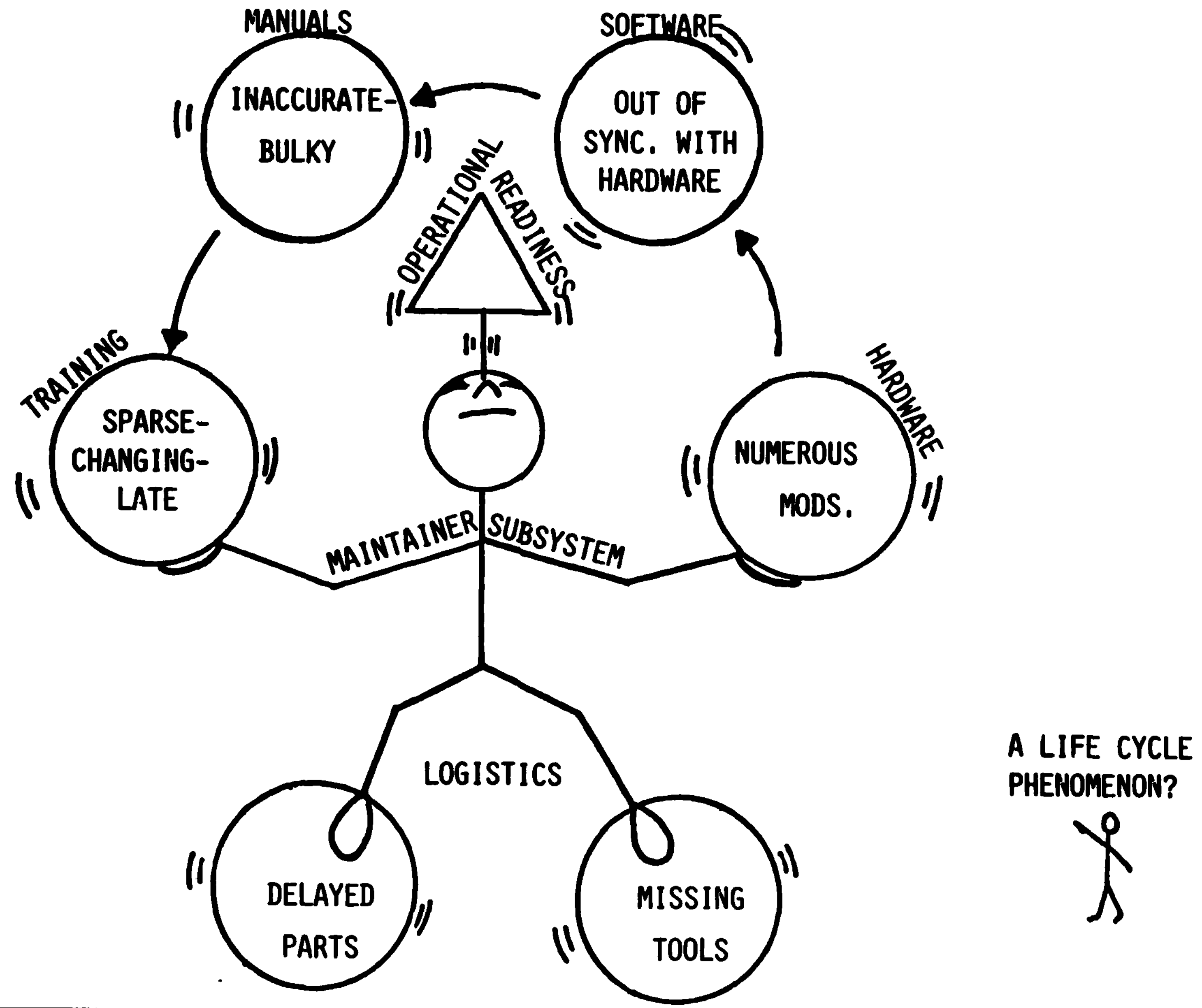
Tank hardware considerations were the driving force in the M1 development and acquisition cycle. A systematic effort was not made early on to integrate requirements for BITE/TMDE hardware with those for maintenance personnel, test procedures, or other technical documentation. BITE/TMDE requirements or constraints were never meaningfully defined or specified in the systems requirements documents. In the main, HMPT considerations had a negligible influence on either the design or development of the fault detection and isolation capabilities of the M1.

SUMMARY

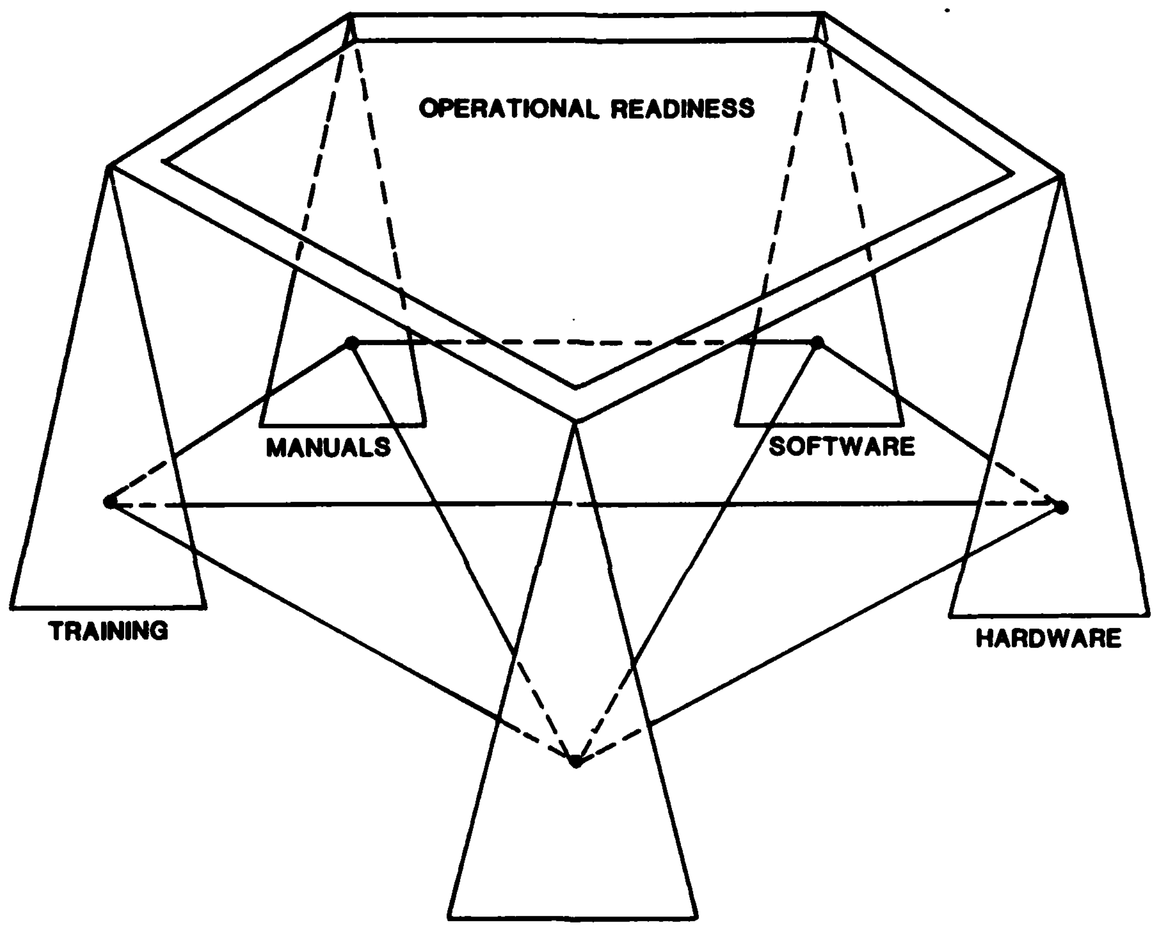
- M1 driven by cost and schedule considerations
- Early design trade-offs made without consideration of long-term ownership
- HMPT considerations had low visibility in early stages of development
- BITE/TMDE requirements never defined or specified
- Performance criteria never established for BITE/TMDE or personnel during DT/OT testing
- Inadequate planning and testing for logistics supportability
- Decisionmakers not given meaningful information to judge effectiveness of BITE/TMDE performance in the hands of soldiers

The acquisition and early operational cycle of the M1 Fault Detection and Isolation Subsystem can be characterized as turbulent with respect to changes in hardware and the resulting need to modify test-set software, TMs, and training. This turbulence existed as of late 1983. Whether the turbulence is abating is still not clear, but available information suggests that some degree of turbulence still exists with respect to:

- Troubleshooting skills
- Test sets (in particular STE/M1)
- Manuals
- Training
- Training devices


MANUALS
INACCURATE-
BULKY
SOFTWARE
OUT OF
SYNC. WITH
HARDWARE
OPERATIONAL
READINESS
TRAINING
SPARSE-
CHANGING-
LATE
HARDWARE
NUMEROUS
MODS.
MAINTAINER
SUBSYSTEM
LOGISTICS
DELAYED
PARTS
MISSING
TOOLS
A LIFE CYCLE
PHENOMENON?

Reverse engineering of the M1 illustrates the impact of sequential system planning and design with hardware leading the way, followed by the supporting subsystems and components. Couple this with frequent hardware changes subsequent to IOC and the operational cycle merely becomes an extension of the acquisition cycle.



Concurrent planning and development:
Leads to an optimally combat ready system

That's the ticket!

Acronyms

AD	Advanced development
ADP	Advanced development phase
ASI	Additional skill identifier
ATE	Automatic test equipment
ATP	Alternate test procedures
BITE	Built-in test equipment
BOIP	Basis of issue plan
COFT	Conduct of fire trainer
CSA	Chief of Staff of the Army
DCST	Deputy Chief of Staff, Training
DID	Data item description
DoD	Department of Defense
DS	Direct support
DSESTS	Direct Support Electrical System Test Set
FDIS	Fault Detection and Isolation Subsystem
FSED	Full-scale engineering development
GPS	Gunner's primary sight
GS	General support
HEL	Human engineering laboratory
HFE	Human factors engineering
IER	Independent evaluation report
ILS	Integrated Logistics System
ITDT	Integrated technical documentation and training
LCSMM	Life Cycle System Management Model
LED	Light-emitting diode
LOA	Letter of agreement
LOS	Line of sight
LSA	Logistics support analysis
MBT	Main battle tank
MBTTF	Main Battle Tank Task Force
MET	Maintenance Evaluation Test
MMBEMD	Mean miles between essential maintenance demands
MN	Material Need
MN/ED	Material Need (Engineering Development)
MS	Maintenance support
NET	New equipment training
OTI	Operational Test I
PM	Program Manager
PMO	Program Management Office
POI	Programs of Instruction
PVT	Production validation test
RAM-D	Reliability, availability, maintainability-durability
RFP	Request for proposal
SPA	Skill performance aids
STE/M1	Simplified Test Equipment
TDR	Training device requirements
TIS	Thermal-Imaging Subsystem
TISTS	Thermal-Imaging Subsystem Test Set
TM	Technical Manual
TMDE	Test measurement and diagnostic equipment
TOE	Table of organization and equipment
TSSG	Tank Special Study Group
TSTS	Thermal System Test Set
USAREUR	U.S. Army Europe